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PROCEEDINGS
of
The Institute of Radio Engineers

D B Wilson

Form for Change of Mailing Address or Business Title on Page XXIX

Institute of Radio Engineers Forthcoming Meetings

TWENTIETH ANNIVERSARY CONVENTION
Pittsburgh, Penna.
April 7, 8, 9, 1932

BUFFALO-NIAGARA SECTION
April 18, 1932

CINCINNATI SECTION
April 19, 1932 May 17, 1932

DETROIT SECTION
April 15, 1932 May 20, 1932

LOS ANGELES SECTION
April 19, 1932 May 17, 1932

NEW YORK MEETINGS
May 4, 1932 June 1, 1932

ROCHESTER SECTION
April 7, 1932 April 28, 1932

TORONTO SECTION
April 16, 1932

WASHINGTON SECTION
April 14, 1932 May 12, 1932

EDMOND BRUCE
Recipient of the Morris Liebmann Memorial Prize for 1932

Edmond Bruce was born in St. Louis, Mo., on September 28, 1899. He received his early education in that city, Cambridge, Mass., Brooklyn, N. Y., and Washington, D. C.

In March, 1917, he left high school to join the U. S. Navy and after serving in various capacities was eventually located at Otter Cliffs, Maine, as chief radio electrician in the transatlantic communication service.

Upon leaving the navy, he studied at George Washington University in 1919 and at Massachusetts Institute of Technology from 1920 to 1924, receiving his batchelor's degree in electrical communication. During these years he also did engineering work for the Clapp-Eastham Company.

He entered the services of the Western Electric Company in 1924, and in 1925 became a member of the Bell Telephone Laboratories staff with which organization he is still associated. He has been engaged in the development of short-wave radio receivers and field strength measuring equipment. More recently he has specialized in directive antenna systems for short-wave radio communication, and it is for his work in this latter field that the Morris Liebmann Memorial Prize was awarded him.

He is a member of the Tau Beta Pi honorary engineering fraternity. He became an Associate member of the Institute of Radio Engineers in 1926, transferring to the Member grade in 1929.

INSTITUTE NEWS AND RADIO NOTES

March Meeting of the Board of Directors

The March meeting of the Board of Directors was held on the 2nd in New York City, and those present were: W. G. Cady, president; Melville Eastham, treasurer; Alfred N. Goldsmith, editor; Arthur Batcheller, O. H. Caldwell, J. V. L. Hogan, H. W. Houck, C. M. Jansky, Jr., R. H. Marriott, E. L. Nelson, William Wilson, and H. P. Westman, secretary.

Applications for transfer to the Member grade in the names of A. V. Baldwin, A. V. Eastman, and E. C. Nye were approved as were also eighty-eight applications for the Associate grade and three applications for the Junior grade of membership.

The Board observed with deep regret the passing of General G. A. Ferrié of Paris who was the latest recipient of the Institute Medal of Honor, and noted with similar feelings the passing of Secretary F. L. Hutchinson of the American Institute of Electrical Engineers.

A request from the American Association for the Advancement of Science for a list of the new members admitted to the Institute during 1930 so that these individuals might be offered membership in the A.A.A.S. without payment of the regular initiation fee was approved, the supplying of this list being a part of the duty of the Institute as a member body of the A.A.A.S.

The Awards Committee submitted its recommendations for recipients of the two annual Institute awards. These recommendations were approved and are as follows:

"That the Institute Medal of Honor for 1932 be bestowed upon Dr. A. E. Kennelly for his studies of radio propagation phenomena and his contributions to the theory and measurement methods in the alternating-current circuit field which now have extensive radio application."

"That the Morris Liebmann Memorial Prize be given to Edmond Bruce for his theoretical investigations and field developments in the domain of directional antennas."

A report on the work of the Emergency Employment Committee indicated that contributions from the membership totaling $1,800 had been received. Approximately $1,000 had been spent and the committee had placed nine members in permanent employment, put thirty-four in contact with temporary or permanent jobs, and employed directly forty-eight on a broadcast reception survey in twenty states.

The Institute was invited to be represented on a newly formed committee known as the American Committee on the Marking of Obstructions to Air Navigation, and R. T. Rossi was appointed the Institute's representative.

An invitation to the Institute to be represented at a celebration of the One Hundredth Anniversary of the electrical discoveries of Joseph Henry to be held on April 25th at the National Academy of Science in Washington, D.C., was accepted, and J. H. Dellinger appointed the Institute's representative at this function.

As the first Wednesday in April is the day before the opening of the Twentieth Anniversary Convention in Pittsburgh, it was decided that the next meeting of the Board of Directors should be held on Wednesday, March 30th.

Radio Transmissions of Standard Frequency

The Bureau of Standards transmits standard frequencies from its station WWV, Washington, D. C., every Tuesday. The transmissions are on 5000 kilocycles, and are given continuously from 2:00 to 4:00 P.M., and from 10:00 P.M. to 12:00 midnight, Eastern Standard Time. (From October, 1931, to March, 1932, inclusive, the evening schedule was two hours earlier.) This service may be used by transmitting stations in adjusting their transmitters to exact frequency, and by the public in calibrating frequency standards and transmitting and receiving apparatus. The transmissions can be heard and utilized by stations equipped for continuous-wave reception throughout the United States although not with certainty in some places. The accuracy of the frequency is at all times better than one cycle (one in five million).

From the 5000 kilocycles any frequency may be checked by the method of harmonics. Information on how to receive and utilize the signals is given in pamphlets obtainable on request addressed to the Bureau of Standards, Washington, D. C.

The transmissions consist mainly of continuous, unkeyed carrier frequency, giving a continuous whistle in the phones when received with an oscillatory receiving set. For the first five minutes there are transmitted the general call (CQ de WWV) and announcement of the frequency. The frequency and the call letters of the station (WWV) are given every ten minutes thereafter.

Supplementary experimental transmissions are made at other times. Some of these are made with modulated waves, at various modulation frequencies. Information regarding proposed supplementary transmis-

sions is given by radio during the regular transmissions, and also announced in the newspapers.

The Bureau desires to receive reports on the transmissions, especially because radio transmission phenomena change with the season of the year. The data desired are approximate field intensity, fading characteristics, and the suitability of the transmissions for frequency measurements. It is suggested that in reporting on intensities, the following designations be used where field intensity measurement apparatus is not used: (1) hardly perceptible, unreadable; (2) weak, readable now and then; (3) fairly good, readable with difficulty; (4) good, readable; (5) very good, perfectly readable. A statement as to whether fading is present or not is desired, and if so, its characteristics, such as time between peaks of signal intensity. Statements as to type of receiving set and type of antenna used are also desired. The Bureau would also appreciate reports on the use of the transmissions for purposes of frequency measurement or control.

All reports and letters regarding the transmissions should be addressed to the Bureau of Standards, Washington, D. C.

Proceedings Binders

Binders for the PROCEEDINGS, which may be used as permanent covers or for temporary transfer purposes, are available from the Institute office. These binders are handsome Spanish grain fabrikoid, in blue and gold. Wire fasteners hold each copy in place and permit removal of any issue from the binder in a few seconds. All issues lie flat when the binder is open. Each binder will accommodate a full year's supply of the PROCEEDINGS and they are available at one dollar and seventy five cents ($1.75) each. Your name, or PROCEEDINGS volume number, will be stamped in gold for fifty cents (50¢) additional.

Bound Volumes

The twelve issues of the PROCEEDINGS published during 1931 are now available in blue buckram binding to members of the Institute at nine dollars and fifty cents ($9.50) per volume. The price to nonmembers of the Institute is twelve ($12.00) dollars per volume.

1931 Index to the Proceedings

The 1931 Index to the PROCEEDINGS is issued as a supplement to the January, 1932, issue. The Institute will mail extra copies upon request.

Committee Work

Admissions Committee

A meeting of the Admissions Committee was held on March 2 with A. F. Van Dyck, chairman; H. C. Gawler, C. M. Jansky, Jr., A. V. Loughren, E. R. Shute, and H. P. Westman, secretary, in attendance.

The committee considered six applications for transfer to the grade of Member of which four were approved. Of the four applications considered for admission to the grade of Member, only one was approved.

Awards Committee

The Awards Committee held its only meeting of the year on March 2 with William Wilson, chairman, and Alfred N. Goldsmith in attendance. Opinions of two other members of the committee who were unable to be present at the meeting were available to the committee in reaching its decision.

The findings of the committee which were approved by the Board of Directors are given in the report of the March meeting of the Board of Directors.

Membership Committee

A meeting of the Membership Committee was held on the 2nd of March and was attended by H. C. Gawler, chairman; C. R. Rowe, J. E. Smith, and A. M. Trogner.

The committee agreed that the faculty members of the leading engineering schools should be circularized advising them of the new Student grade of membership.

In addition, it was thought advisable to request the executives of sections to submit the names of those in their sections who are eligible for advancement in membership grade together with such details as are necessary in order that the applications may be placed before the Admissions Committee for consideration.

New York Program Committee

On March 7 a meeting of the New York Program Committee was held and attended by E. R. Shute, chairman; H. C. Gawler, H. E. Hallborg, C. W. Horn, R. H. Ranger, J. L. Reynolds, and H. P. Westman, secretary.

As no New York meeting will be held in April, the committee decided upon the subjects to be covered at the May, June, and September meetings.

STANDARDIZATION

Sectional Committee on Radio—ASA

Subcommittee on Definitions

Three meetings of the Subcommittee on Definitions of the Sectional Committee on Radio were held on February 11, February 19, and March 3 in New York City.

The purpose of this committee is to review the definitions which were submitted to the Sectional Committee on Radio by its technical committees for approval as ASA standards. These definitions were not approved by the Sectional Committee in view of some recent standards reports issued by a Sectional Committee on Electrical Definitions, there being some conflict in the two sets of proposed standards. Accordingly, the committee has devoted its entire time to a consideration of these two sets of standards and has attempted to set up new standards which would be satisfactory to both committees.

Haraden Pratt, chairman; C. F. Wiebusch (representing H. A. Frederick), William Wilson and B. Dudley, secretary, attended the February 11 meeting.

Haraden Pratt, chairman; R. H. Langley, C. F. Wiebusch (representing H. A. Frederick), R. M. Wilmotte, William Wilson, and B. Dudley, secretary, attended the February 19 meeting.

The March 3 meeting was attended by Haraden Pratt, chairman; J. Blanchard (representing William Wilson), R. H. Langley, C. F. Wiebusch (representing H. A. Frederick), Irving Wolff, and B. Dudley, secretary.

Technical Committee on Electro-Acoustic Devices—IRE

A meeting of the Institute's Technical Committee on Electro-Acoustic Devices was held on March 5 in New York City, those in attendance being E. D. Cook, chairman; L. G. Bostwick, Benjamin Olney, and Beverly Dudley, secretary.

The committee continued its examination of the definitions on electro-acoustic devices which appear in the 1931 Report of the Standards Committee and recommended a number of changes therein. It also considered further the possibility of establishing acceptable conditions for the measuring of the acoustic output of radio receivers, loud speakers, and other electro-acoustic devices. Although the need for such tests is apparent, it was the opinion of the committee that it would be impossible at the present time to specify measuring conditions which would permit measurements having reasonably accurate significance to manufacturers of electro-acoustic devices.

Technical Committee on Radio Receivers—IRE

The Technical Committee on Radio Receivers of the Institute held a meeting on March 3 in New York City those present being H. A. Wheeler, chairman; E. T. Dickey, Lloyd Espenschied, Malcolm Ferris (representing C. M. Burrill), V. M. Graham, V. Ford Greaves, F. A. Hinners, R. H. Langley, F. A. Polkinghorn, F. H. Rettenmeyer (nonmember), A. E. Thiessen, L. P. Tuckerman, (representing C. E. Brigham), Lincoln Walsh, E. W. Wilby (representing David Grimes), W. T. Wintringham (nonmember), and Beverly Dudley, secretary.

The committee considered the problem of interference and selectivity in the broadcast band which confronts the Federal Radio Commission. It was thought that its new proposed two-signal method of determining selectivity of radio receivers would throw some light on a number of interference problems which would be of value both to the Commission and to the manufacturer of receivers.

The possibility of establishing figures of merit for such receiver characteristics as frequency range, sensitivity, amplitude-response characteristics, load capacity, selectivity, generated noise, stability, and shielding was discussed, and an attempt will be made to incorporate such in the report of the committee.

It was considered desirable to specify the sensitivity of a radio receiver in terms of decibels below a reference level of one volt as an alternative method to the present system of indicating the sensitivity in terms of microvolts impressed upon the receiver to give standard output.

The committee continued its review of the material appearing under the heading "Standard Tests of Broadcast Receivers" and made a number of suggested revisions therein.

Technical Committee on Transmitters and Antennas—IRE

On February 8 a meeting of the Technical Committee on Transmitters and Antennas was held in New York. William Wilson, chairman; J. B. Blanchard (nonmember), W. W. Brown, A. B. Camberlain, H. E. Hallborg, D. G. Little, Haraden Pratt, Paul Watson, and B. Dudley, secretary, were in attendance.

It was not considered advisable to attempt to establish standards on materials used in radio transmitting equipment in view of the limited knowledge of the characteristics of the various physical materials when exposed to high field intensities of very high frequencies.

The committee reviewed the section on "Tentative Suggested Methods of Testing and Rating Radio Transmitters and Antennas" published in the 1931 report. It made a number of changes in this

section, and in order to facilitate matters several of the members of the committee were requested to prepare individual reports on specified portions of this section of the 1931 report.

The committee thought it desirable to include in the next report a bibliography on frequency measurements.

For Improved Radio Broadcast Reception

Mr. O. H. Caldwell, former Federal Radio Commissioner, who is now Editor of the magazines *Electronics* and *Radio Retailing*, has brought to the attention of the Institute membership a campaign for improved radio reception which in turn will make for greater popularity in radio, greater sales of new sets, and immediate sales of replacement tubes, parts, etc.

A nation-wide campaign will be started this spring to bring better radio reception conditions to millions of radio listeners—a campaign which will prove of tremendous benefit to the listening public, dealers, jobbers, manufacturers, and broadcasters.

With the help of broadcast stations, newspapers, magazine articles, etc., the listening public will be reminded and informed of the standards of good reception which it should be enjoying, to wit:

1. Freedom from noise, clicks, and buzzes
2. Fidelity of tone—"reality"
3. Ability to hear clearly all near-by stations

Every reader will admit that radio reception conditions in millions of homes and for millions of listeners can be greatly improved through calls and overhaulings by local dealers or servicemen.

Radio dealers are, therefore, urged to begin at once making canvasses of their neighborhoods to improve listener's reception. Such canvasses and calls will open many opportunities for tube replacement, antenna reconstruction, parts sales, etc., besides leading to sales of many new sets.

In this work of bringing "satisfactory radio" to customers, the industry will have its way paved by informative broadcasts over the great broadcast chains telling the listener about the standards of good reception he should be getting and by frequent 20-word reminder announcements, morning, noon, and night urging the listener to "see your nearest radio dealer."

All up and down the industry all forces are thus being marshalled to bring to every home "satisfactory radio" and in this effort every member of the Institute can help.

Institute Meetings

Buffalo-Niagara Section

A meeting of the Buffalo-Niagara Section was held on February 16 at the University of Buffalo, L. Grant Hector, chairman, presiding.

A paper on "Unusual Features of Broadcast Transmitter Design and Operation Employed in Station WBEN" by L. C. F. Horle, consulting engineer and R. J. Kingsley, chief engineer of WBEN, was presented by Mr. Kingsley.

The speaker pointed out that the first problem was that of the location of the transmitter with respect to the area it was intended to serve and the distribution of population in that area. With these thoughts in view, the transmitter was located about thirteen miles north of the Hotel Statler in Buffalo in which the main studios are. This is a sparsely populated section.

The antenna was designed to give a directional field pattern, and this characteristic was increased by the erection of a reflector system. For continuity and flexibility of operation an emergency transmitter is located at the hotel, and many phases of its operation are automatic in nature.

Power for the main transmitter is obtained from the Niagara Falls power station which is supplemented by a steam turbogenerator station near Buffalo. Power for the studio and emergency transmitter is furnished by the latter plant. For emergency purposes a 400-volt storage battery is maintained at the hotel.

The antenna of the main transmitter is protected from the effects of heavy sleet storms prevalent in the Buffalo section of the country by the use of auxiliary apparatus which permits the flow of 110 amperes of 25-cycle current into the wires for sleet melting during regular operation. This is made possible through the utilization of suitable chokes and condensers in the antenna circuit.

The installation of many duplicate pieces of apparatus and the automatic starting of the emergency transmitter with failure of the main transmitter insures against most accidents which might happen. Testing of the transmitter is facilitated by the use of a dummy antenna.

Messrs. Brown, Hector, Horle, Huntsinger, Kingsley, McNaab and several others of the 66 members and guests in attendance entered into the discussion of the paper.

The March meeting of the Buffalo-Niagara Section was held on the 8th at the University of Buffalo, L. Grant Hector, chairman, presiding.

Henry Argento of the Radio Frequency Laboratories presented a paper on "High-Frequency Measurements."

The author pointed out the advantages of the reactance variation method of measurement, especially over the resistance variation method.

A number of the 32 members and guests in attendance at the meeting participated in a general discussion which followed the paper.

Cincinnati Section

The February 16 meeting of the Cincinnati Section was held at the University of Cincinnati, and was presided over by C. E. Kilgour, chairman and W. C. Osterbrok, vice chairman.

The first paper on "A Semiautomatic Device for Recording Vacuum Tube Characteristics" was presented by C. G. Felix. The author presented an outline of the equipment necessary and the time required in the ordinary methods of obtaining tube characteristic curves pointing out the need for apparatus which would make any curve in a short time, preserve a record of it, and enable direct and rapid comparisons to be made.

Slides were shown giving diagrams of circuits which would give regular variations in applied voltages and record the changes which might be expected in the operating range of a normal tube. The use of inexpensive equipment arranged in a simple bridge circuit to indicate such changes with a reasonably high degree of accuracy was also shown. Photographs of apparatus in use and sample curves as drawn were presented as illustrations.

The second paper of the evening by C. E. Kilgour and J. M. Glessner was on "Distortionless Output from the Diode Detector." The theoretical ideal detector was discussed and the action of familiar tubes when connected as diodes outlined. The effects of such a detector on the selectivity and the power output requirements which the preceding circuits must fulfill were covered. The use of diode detectors to obtain bias voltage for amplifier stages permitting automatic volume control and the possible applications of the diode in push-pull and voltage doubling circuits were discussed.

In closing, the author outlined the causes of distortion present in such devices and methods of eliminating such. Both papers were discussed by a number of the 43 members and guests in attendance.

Connecticut Valley Section

L. F. Curtis, chairman, presided at the January 28 meeting of the Connecticut Valley Section held at the Hotel Garde, Hartford, Conn.

"A Blackboard Discussion of Antennas and Transmission Lines" was presented by E. A. Laport of the Westinghouse Electric and Manufacturing Company. Mr. Laport covered the characteristics of transmitting antennas, particularly grounded types such as are used for broadcast stations. The effect of antenna design on directional characteristics and angle of radiation was discussed and a simplified method of calculating antenna performance devised by the author was described. Operating characteristics of transmitting lines, especially those of the two-wire untuned type were covered and practical operating data given.

The paper was discussed by several of the 42 members and guests in attendance.

The February meeting of the Connecticut Valley Section was held on the 18th at the Hotel Garde in Hartford, Conn., H. W. Holt, vice chairman, presiding.

"Class B High Power Audio Amplifiers and Modulators" was the subject of a paper by J. A. Hutcheson of the Westinghouse Electric and Manufacturing Company.

Mr. Hutcheson's paper covered the use of comparatively small tubes to obtain large audio outputs by means of class B audio amplifier operation. Charts illustrating the performance of such tubes were shown.

At the completion of the talk those present were invited to attend a demonstration of a 30-watt class B public address amplifier given at the offices of the American Radio Relay League in West Hartford, Conn. Practically all of the 48 members and guests in attendance took advantage of this opportunity.

Detroit Section

The Detroit Section of the Institute were the guests of the Detroit-Ann Arbor Section of the American Institute of Electrical Engineers at a meeting on February 16 held at the Michigan Bell Telephone Company auditorium in Detroit and presided over by J. J. Shoemaker of the A.I.E.E. Section.

J. O. Perrine of the American Telephone and Telegraph Company presented a paper on "Fundamental Physical and Psychological Aspects of Television." The speaker who treated the subject in a non-technical fashion made effective use of apparatus to demonstrate the points he desired to bring out. He first demonstrated the operation of a light sensitive cell showing how a beam of light impinging thereon caused a change in current in an associated electrical circuit. The need

for vacuum tube amplifiers, scanning disks, and a number of other pieces of associated equipment was pointed out, and the television system as developed by the Bell Telephone Laboratories was described. The speaker next outlined some of the inherent difficulties encountered in television, pointing out that although a frequency band of 10 kilocycles was sufficiently satisfactory for aural radio reception, it certainly was not satisfactory for television purposes.

The meeting was attended by approximately 400.

Los Angeles Section

E. H. Schreiber, chairman, presided at the February 16 meeting of the Los Angeles Section held in the Mayfair Hotel in Los Angeles.

A paper on "Aeronautic Radio" was presented by Herbert Hoover, Jr., consulting engineer for Transcontinental and Western Air, Inc.

In his talk he discussed the development of radio as an aid to commercial aerial transportation from its inception following the world war to its present state. Descriptions were given of European equipment and a comparison made with American types. In closing he pointed out the great efficiency of radio communication in this field and the excellent coöperation between the various transport operators.

The meeting was attended by 85 members and guests, 30 of whom attended the informal dinner which preceded it.

New York Meeting

The March 2 New York meeting of the Institute held in the Engineering Societies Building in New York City was presided over by President Cady and devoted to the subject of "Radio City."

M. H. Aylesworth, President of the National Broadcasting Company, gave a short introductory address outlining the history of broadcasting in this country and the part it is playing in modern life. He then introduced O. B. Hanson, Manager of Technical Operations and Engineering of the National Broadcasting Company who discussed the problems which must be dealt with in the design, construction, and furnishing of the most modern radio studio project yet undertaken. The general structural difficulties and their solutions were described together with the methods of handling sound insulation and absorption, ventilation, air conditioning, and other services necessary in the construction of the large studio such as is being built in New York in "Radio City." In addition to a description of the technical features of this project, a general outline of its scope was given.

The meeting was attended by 275 members and guests.

Philadelphia Section

At the January 21 meeting of the Philadelphia Section held at the Engineers Club and presided over by Ralph Hayes, a paper on "Problems in the Latest Development of Transoceanic Radio Telephony" was presented by Ralph Bown of the American Telephone and Telegraph Company.

In addition to covering the technical aspects of the transmitters and receivers for such purposes, the author discussed the relative merits of the high and low radio frequency transmission channels. The paper was discussed by a number of the one hundred and thirty-nine members and guests who attended the meeting.

Rochester Section

A meeting of the Rochester Section was held on January 14 at the Sagamore Hotel, George C. Wright presiding.

An historical talk on the growth of wireless from its early conception to the present-day apparatus including modern improvements was given by A. E. Soderholm under the title of "Program Service Systems."

The attendance at the meeting totaled sixty-seven.

A February meeting was held on the 11th at the Sagamore Hotel, Howard Brown, chairman, presiding.

The evening was devoted to a symposium on the operation of a broadcast transmitting station. William Fay, manager of WHAM, spoke on "How a Modern Radio Station Functions"; J. J. Long, chief engineer of WHAM discussed "Station Operation"; Jack Lee covered "Topic Production of Programs"; Ben Weaver explained "How Programs are Sold"; and Lew Stark discussed out the "Pitfalls of Announcers."

It was pointed out that a radio station's duty is to the public and those in charge must be ever mindful of its responsibility if the station is to receive general approbation. As can be seen from the titles of the papers delivered, the details of operation that must constantly be intelligently dealt with were thoroughly delved into.

In addition to these papers, some vocal numbers were given by William Fay, Ben Weaver, and Jack Lee. Helen Ankner entertained with piano selections. All of the entertainers were members of the staff of WHAM the studios of which station were open for inspection following the meeting.

The meeting was attended by 325 members and guests.

San Francisco Section

On February 12 the San Francisco Section held a joint meeting with the San Francisco Section of the American Institute of Electrical Engineers and the Signal Corps Association which was held at the Pacific Gas and Electric Auditorium and presided over by E. A. Crellin of the A.I.E.E. section.

A paper on "Overseas Radiotelephone Service of the Bell System" was presented by W. H. Harrison.

The speaker traced the development of international telephone service from the earliest beginnings up to the recent radio extensions. He described the essential features of these radio links both from the technical and operating aspects and also touched upon their future possibilities.

The meeting was attended by 600 members and guests of whom 121 were present at an informal dinner which preceded it. Of those in attendance a large number visited the transpacific transmitting station near Dixon, California, which kept open house the next day for their benefit.

Seattle Section

The February meeting of the Seattle Section was held on the 19th, L. C. Austin, chairman, presiding.

This was a joint meeting with the American Institute of Electrical Engineers and the attendance totaled over 300.

W. H. Harrison presented at this meeting the same paper that he presented at the San Francisco Section on February 12.

Toronto Section

A meeting of the Toronto Section was held on the 6th of January at the University of Toronto, F. K. Dalton, chairman, presiding.

A paper by Weston Wrigley on "Living Conditions in Europe" was presented and covered conditions observed by the speaker while on a tour of various European countries. The various outstanding differences between life in Canada and Europe were outlined.

The second paper of the evening by W. Cook comprised a detailed account of the various types of radio broadcasts and receivers which are in vogue at the present time in Europe. This also was the result of a tour of a number of European countries made by the author.

Messrs. Choat, Fox, McCardle, and Meredith, of the forty-one members and guests, discussed the paper.

The second meeting of the Toronto Section was held in January on the 27th in the Electrical Building, University of Toronto, F. K. Dalton, chairman, presiding.

Two papers were presented by L. M. Perkins, chief engineer of the Erie Resistor Corporation. The first of these "Resistors and their Application to Radio Sets" outlined in detail the problems involved in the manufacture of various types of resistors. By means of a cathode ray oscillograph the instantaneous variations in resistors when subjected to low and high voltages were demonstrated.

The second paper by the same author on "Amplitude-Frequency Modulation and Side Bands" was of a mathematical nature illustrated by slides showing vector diagrams of the amplitude and frequency systems of modulation and the effects on side bands.

These paper were discussed by Messrs. Andre, Cook, Fox, Oxley, Smith and others of the sixty-five members and guests in attendance.

A meeting of the Toronto Section was held on February 17 at the University of Toronto, G. E. Pipe presiding.

At this meeting the paper on broadcast station WBEN by Messrs. Kingsley and Horle was presented. This paper is the one delivered at the February 16 meeting of the Buffalo-Niagara Section.

The attendance at the meeting totaled 60.

Washington Section

The February meeting of the Washington Section was held at the Continental Hotel on the 11th, J. H. Dellinger, chairman, presiding.

E. G. Lapham of the Bureau of Standards presented a paper describing piezo-electric oscillators used in the control of the standard frequency transmissions from the Bureau of Standards. The paper also included a brief account of the method of measurement at the Bureau.

It was discussed by Doctors Dellinger, Dorsey and several others of the 32 members and guests present at the meeting.

Personal Mention

R. C. Ballard, formerly of the RCA Victor Company has become television engineer for the U. S. Radio and Television Corporation, Marion, Ind.

E. C. Carlson previously with the Radio Corporation of America has joined the engineering staff of U.S. Radio and Television Corporation.

Lieutenant G. J. Crosby, U.S.N., has been transferred from the U.S.S. Rochester to the U.S.S. Memphis.

Previously with the Gramaphone Company, F. W. Dawe has become test designs engineer for E. K. Cole, Ltd., at Southend, England.

Gerald Deakin has left the New York office of the International Telephone and Telegraph Company to become vice president and European technical director with headquarters in London.

Formerly with Wired Radio, V. D. Hauck has become a radio engineer for the DeForest Radio Company.

Previously with the Patent Development Company, C. C. Henry has become chief engineer of Lear Developments, Inc., of Chicago.

Formerly with the Atwater-Kent Manufacturing Company, V. C. McNabb has become chief engineer of the Rudolph Wurlitzer Company in North Tonawanda, N.Y.

John Mauran has left RCA Photophone to join the RCA Victor staff as liaison engineer.

John H. Miller formerly with the Jewell Electric Instrument Company is now engineer-in-charge of the radio division of the Weston Electric Instrument Corporation in Newark.

H. L. Olesen, previously with the Jewell Electric Instrument Company has become manager of the radio sales department of Weston Electric Instrument Corporation.

Previously with Philco Products, Ltd., A. M. Patience is now manager of the radio and electrical division of Hayes Wheels and Forgings, Ltd., of Chatham, Ontario, Canada.

Formerly technical editor of the *Citizen's Radio Call Book* magazine, R. K. Pew has become a development engineer for Grigsby Grunow Company in Chicago.

OBITUARY

With deepest regret the Institute records the death of

Gustave A. Ferrié

The death on February 16 of General Ferrié has taken from France and the world not only an outstanding communications and military engineer but also a personality beloved by all who had come in contact with him.

It was the privilege of the Institute to present to him in 1931 its Medal of Honor in recognition of his pioneer work in the upbuilding of radio communication in France and in the world, his long continued leadership in the communication field, and his outstanding contributions to the organization of international coöperation in radio.

PART II
TECHNICAL PAPERS

Proceedings of the Institute of Radio Engineers
Volume 20, Number 4 *April, 1932*

EMPIRICAL STANDARDS FOR BROADCAST ALLOCATION*

BY

A. D. RING

(Senior Engineer, Engineering Division, Federal Radio Commission, Washington, D.C.)

Summary—*The method used by the Engineering Division of the Federal Radio Commission in determining empirical standards of reception, interference, and service area is explained, for consideration in connection with the engineering aspects of the allocation of radio broadcast facilities.*

The average good service areas of 100-watt local channel stations, 250- to 1000-watt regional channel stations, 5000- to 10,000-watt high power regional channel stations, and 5000- to 50,000-watt clear channel stations are defined with reference to the voltage intensity ratio of the desired signal to the undesired signal incidental to specified mileage and kilocycle separations between stations.

It is pointed out that the empirical standards will be changed when justified by additional data and further development of the art along the lines of suppression of sky-wave radiation, synchronization, improvements in reception conditions, etc.

Various tables and graphs are included.

IN MAKING recommendations to the Commission and giving testimony at hearings before the Commission on applications for broadcast stations in the band 550–1500 kilocycles, the engineering division of the Federal Radio Commission is confronted with the problem of going into the details of broadcast allocation engineering. To insure uniformity, it has been necessary to adopt many empirical standards of reception, interference, service area, etc., that have not previously been published. In developing these standards, all sources of information now available have been used, and as more and more technical broadcast data are obtained, these standards will necessarily change. Since many of the standards are also based on present-day average receiving sets, average standards of listeners, present design of antennas, etc., they will of course be changed as the art progresses.

The empirical standards set out below were prepared and averaged upon data obtained from the following sources:

1. Evidence given in hearings before the Commission by expert radio engineers.

2. Experience of engineers of the Engineering Division, based upon their personal experiences and observations in the field and on studies of reports and publications on the subject.

* Decimal classification: R007×R550. Original manuscript received by the Institute, November 11, 1931.

3. Averages of many hundred field intensity measurements made by the Radio Division, Department of Commerce.

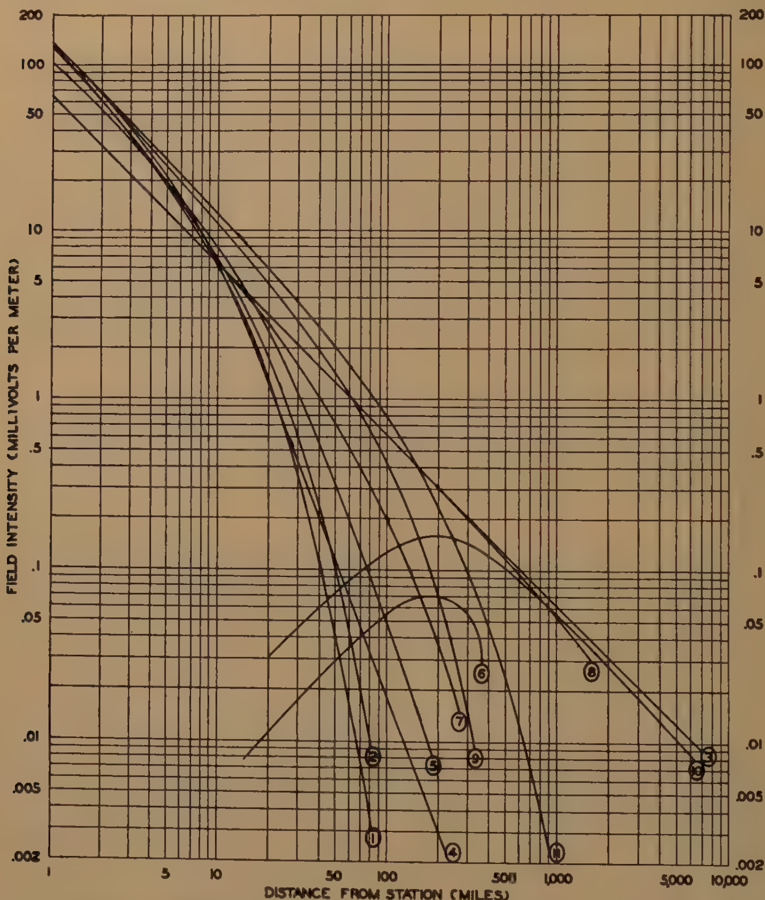

Fig. 1—Field intensities of broadcast stations as derived from formulas and observed values.

(1) Bell Laboratories—ground wave:

$$E = \frac{19.42 \times 10^4}{D} \times \sqrt{P_{rkw}}\, e^{-101.5 a D/\lambda^{0.6}}$$

a = 0.0246 for suburban territory in northeastern U. S.

(Proc. I.R.E., August, 1929)

(2) Hogan—ground wave:

$$E = \frac{5.8\sqrt{P_r}}{D}\, e^{-aD\sqrt{f}}$$

a = 0.002 for Detroit territory.

(Testimony before the Federal Radio Commission September 22, 1930, Docket 790, WWJ)

(3) Hogan—night intensity:

$$E = \frac{2.9\sqrt{P_r}}{D}$$

(Testimony before the Federal Radio Commission February 18, 1930, Docket 679, WTMJ)

(4) van der Pol—ground wave:

$$E = 300\frac{\sqrt{P_{kw}}}{D_{km}} \times \frac{2 + 0.3p}{2 + p + 0.6p^2}$$

$$p = \frac{\pi D_{km}}{6.1^{15}\ \delta\lambda^2_{km}}$$

(C.C.I.R., Document No. 70, March 31, 1931, prepared by the International Broadcasting Union)

(5) Eckersley—ground wave:

(Proc. I.R.E., July, 1930)

(6) Eckersley—maximum sky wave:

(Proc. I.R.E., July, 1930)

(7) Average of day measurements made by U. S. Supervisors of Radio:

(8) Average of night measurements made by U. S. Supervisors of Radio:

(9) Barron—ground wave:

$$E = \frac{379\pi hIf}{10^7 D}(1 - a)^D$$

$$a = 0.01$$

(Testimony before the Federal Radio Commission June 26, 1931, Docket 1183, WAAT)

(10) Barron—average sky wave:

$$E = \frac{190\pi hIf\cos\theta}{10^7 D}$$

(Testimony before the Federal Radio Commission, June 26, 1931, Docket 1183, WAAT)

(11) Austin-Cohen—ground wave:

$$E = \frac{300\sqrt{P_r}}{D_{km}}\, a\, \frac{-aD_{km}}{\lambda^{0.6}_{km}}$$

$$a = 0.0014 \text{ for sea water}$$

(C.C.I.R. Document No. 70, February 21, 1931, prepared by the International Broadcasting Union)

These curves are plotted for the following values, unless otherwise noted above:

E = field intensity, millivolts per meter
P_r = radiated power = 500 watts
P_i = antenna power = 1000 watts
a = absorption coefficient
λ = wavelength = 300 meters
D = distance in miles
δ = conductivity of ground = 10^{-13}
f = frequency = 1000 kilocycles per second
h = effective height of transmitting antenna = 105 feet
I = current at base of antenna, amperes = $\sqrt{P_i/R}$
R = total antenna resistance = 10 ohms
θ = angle between ground and sky ray at transmitter.

4. Study of interference reports made by the Radio Division, Department of Commerce, which cover all points in the United States where offices are located.

5. Several complete surveys made on individual stations by radio division and by other engineers, with respect to service area and interference.

6. Various published formulas on radio transmission.

7. Characteristics of receiving sets.

Fig. 1 shows in graphical form the data as derived from the various sources as indicated. Differences between curves are in many cases very large.

During the past year the radio supervisors have made many measurements on the intensity of broadcast stations, both day and night. Fig. 2 shows the results of these measurements which were taken at many points in the United States and represent the actual conditions which are encountered. The plain circles show day measurements, and solid circles night measurements. All of the readings were reduced to a power of one kilowatt before plotting. These measurements were taken on stations of various frequencies within the broadcast band. No attempt was made to differentiate between different portions of the band, between different seasons of the year, or between different geographical areas. Each circle is the average of from 4 to 50 readings taken on one station during a given period.

These measurements represent the largest collection of field intensity measurements that have been taken and undoubtedly come nearest to presenting the average broadcast transmission range in the United States, of any published data. This work of taking measurements is being continued and if subsequent measurements justify it the curve will be changed. The curves given in Fig. 2 are used as the basis for values of field intensity given below. While they may be approximate, they do represent the best present knowledge concerning average radio transmission in the United States. The transmission of a particular sta-

tion over a particular area may depart considerably from these values but to determine that fact the data must be obtained as the result of an individual study of the station. Beyond about 50 miles from a station, with the present type of antenna, the field intensity in general varies ("fading") due to natural phenomena. Under these conditions average values were used.

The problem that is most difficult to solve and at the same time the most important to consider with respect to service on a channel on which more than one station operates simultaneously at night, is the interference range or "nuisance area" of a station. The "nuisance area" of a broadcast station is here defined as that area over which interference may be caused to reception of other stations operating on the same frequency. Generally speaking, the nuisance area is beyond the service range of a station and extends to many times the radius of the good service area. For example, a 1-kilowatt station has an average good service radius of approximately 40 miles and a nuisance radius of about 1000 miles. A 1-kilowatt station located less than 1000 miles from a second 1-kilowatt station will have mutual interference that will limit the good service radius to less than 40 miles.

Interference to broadcast radio reception in its general meaning is defined as any spurious or extraneous sound accompanying radio reception but as used in connection with this work it refers to objectionable sounds which are present over 10 per cent of the time. The good service area of a station is defined as that area in which satisfactory reception free from interference is obtained at least 90 per cent of the time.

The field intensities necessary to render *good* service are divided into three classes depending upon the noise level of the area to be served. The nature of the area and the necessary field intensities are given in Table I as follows:

TABLE I

Area	Signal
Business City	10 millivolts per meter
Residential City	2 " " "
Rural	0.5 " " "

For *fair* service the signal is one-half the above values and for poor service, one-fourth. The figures are all subject to change if the noise level is unusual or fading is experienced.

The average distance over which average stations of various powers can be expected to give the above classes of service are set out in Table II, as follows:

TABLE II

Power (Watts)	Field Intensity (millivolts per meter)	Average Radius (Miles)
50	10	1.4
	2	7.1
	1	13.5
	0.5	25.5
100	10	2.0
	2	10.0
	1	18.5
	0.5	30.0
250	10	3.2
	2	15.0
	1	26.0
	0.5	41.0
500	10	4.5
	2	20.0
	1	33.0
	0.5	51.5
1 kw	10	6.4
	2	26.0
	1	41.0
	0.5	63.0
2.5 kw	10	10.0
	2	35.5
	1	54.5
	0.5	81.0
5 kw	10	13.8
	2	44.5
	1	67.0
	0.5	93.0
10 kw	10	18.5
	2	55.0
	1	81.0
	0.5	115.0
25 kw	10	26.0
	2	71.0
	1	102.0
	0.5	140.0
50 kw	10	31.5
	2	78.0
	1	120.0
	0.5	160.0

The distances in Table II were taken from Fig. 2 (Day). The average of the day reading is taken as determining the service radius of a station and the average of night readings is taken as determining the night nuisance radius. The dotted curve is employed to determine the day nuisance radius. This is not entirely fair as 50 per cent of the night measurements are above the average night curve and since the nuisance area is defined as that area where interference is created over 10 per cent of the time, it is seen from this that the average station may create interference more than 10 per cent of the time whereas the service range of a station is determined by service 90 per cent of the time.

General Order No. 40 of the Federal Radio Commission divides broadcast stations into three classes; namely, clear channel stations, regional stations, and local stations. The dominant station assigned to

a clear channel is presumably given sufficient power to provide service to the large rural areas, and since only one station is assigned to operate at night on such channels, there is no heterodyne interference from other stations in the United States. Other stations which are assigned to the same frequency are restricted in operation to such periods (daylight and limited time) that no interference will be caused to reception of the dominant station.

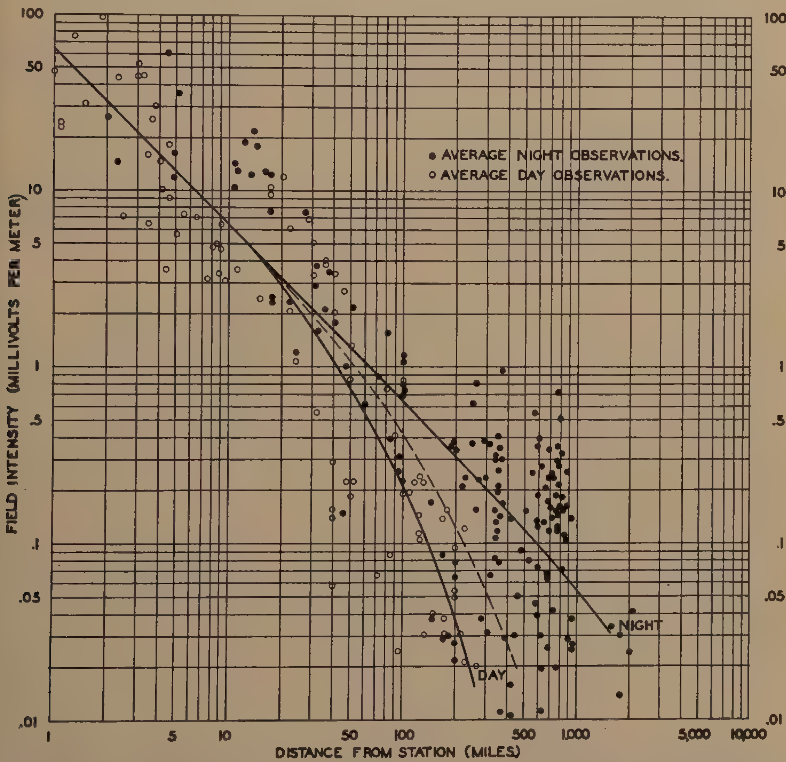

Fig. 2—Observed values of field intensities of broadcast stations. (Observations made by Radio Division, Department of Commerce.) Observed values reduced to antenna power = 1 kw.

The good service area of a clear channel station is empirically defined as that area which receives a field intensity of 0.5 millivolt per meter or more. Fundamentally such a station renders service with field intensities far below this value and consequently to a larger area, but fading and local interference make the service necessarily of an intermittent character. A field intensity of 0.5 millivolt may be subject to fading and will undoubtedly be subject to local interference in many places. The primary purpose of such a station is to serve a center of

population and a large rural area that is not within the service range of any other station and cannot be served economically by any other means than clear channel stations. The power of the dominant clear channel stations ranges from 5 to 50 kilowatts.

Regional channel stations are divided into two groups, high power regional stations and low power regional stations. The low power regional stations operate with night power from 250 to 1000 watts. The high power regional stations are assigned from 5 to 10 kilowatts.

The service area of a regional station is empirically defined as that area receiving a field intensity of one millivolt per meter or more. In making up the separation tables, service tables, and in all references to such stations, this is considered the service area of such stations and they are not given protection and are not expected to give regular service to the area outside this limit. The purpose of the regional stations is to serve a center of population and a small surrounding area or region.

The service area of a local station, which is assigned power not exceeding 100 watts at night, is empirically defined as that area receiving a field intensity of two millivolts per meter or more. Local stations are assigned to serve local centers of population and as the field intensity necessary for good service in populous residential districts is two millivolts per meter, this is the extent to which the separation tables provide for this class of stations.

A summary of the classes of stations and the approximate separation of stations of the same power, assigned the same frequency which is necessary to give the class of service indicated, as determined from Fig. 2, is given in Table III, frequency maintenance assumed to be ±50 cycles per second.

TABLE III

Class of Station	Power (night)	Boundary of Service	Number of Frequencies	Separation
Local	100 w	2 mv/m	6	200 miles
Regional	250 to 1,000 w	1 mv/m	40	1,050 miles
High Power Regional	5,000 to 10,000 w	1 mv/m	4	2,000 miles
Clear	5,000 to 50,000 w	0.5 mv/m and extent of intermittent service	40	Not duplicated

Another factor which must be taken into account in assigning frequencies to broadcast stations is the geographical separation of stations on adjacent frequencies. The present plan of broadcast allocations provides for the assignment of stations on frequencies separated by ten kilocycles. Receiving sets are not at present made which will

give good quality of reception and at the same time be selective enough to accept a signal on one frequency and reject a signal of equal intensity having a frequency 10 kilocycles removed therefrom. The selectivity of receiving sets of different design varies widely. Many confidential quantitative measurements on receiving sets have been made available to the engineering division. From a study of the selectivity of radio receivers and on observation and testimony concerning objectionable interference, it has been determined that on the average the empirical values given in Table IV represent the ratio of field intensity of the desired station to the field intensity of the undesired station, which should be maintained for good service.

TABLE IV

Frequency Separation	Ratio of Desired to Undesired Signals
0	20 to 1*
10 kc	4.65–0.85 to 1.
20 kc	3 times the selectivity at 10 kc
30 kc	7.5 " " " " " "
40 kc	15 " " " " " "

* Frequency maintenance ±50 cycles per second.

Tables V and VI combine the data given in Tables III and IV with the data from the curves in Fig. 2 and give the average separation between stations of different power and class for the same and adjacent frequencies in order to give the average service area specified above.

Tables III, IV, V, and VI assume that the frequency of all stations will be maintained to within ±50 cycles per second of the assigned frequency. With all stations maintaining their frequency within 50 cycles per second of the assignment, the frequency of the average heterodyne note to be expected between stations would be 50 cycles. Under such conditions, it is believed that a ratio of desired to undesired signals of 20 to 1 would give satisfactory reception. If the frequency is maintained within only 500 cycles per second of the assigned frequency, an average heterodyne note of 500 cycles would result and a ratio of desired to undesired signal of 100 to 1 would be considered necessary. This is the condition that will exist until General Order No. 116 of the Federal Radio Commission is effective.

When the heterodyne note has a frequency of 50 cycles, it is a question whether the cross-talk or beat note will be the most objectionable and it may vary somewhat with the type of receiving set used. A ratio of 20 to 1 between desired and undesired signals represents a modulation of the desired signal of 5 per cent at 50 cycles or 5 per cent cross-talk providing each of the stations employ the same percentage of modulation and have comparable programs. These ratios are consid-

ered satisfactory for the majority of rural areas where the standard of reception is not the highest but in the metropolitan areas where programs may be selected from several stations, it is admitted that this is not a sufficiently high standard and the service would not be considered as satisfactory by most listeners.

In determining the mileage separation on adjacent frequencies, in Tables V and VI, the ratio between the desired and undesired signals at 10-kilocycle frequency separation is given as varying from 4.65 to 1 to 0.85 to 1. A study of the characteristics of many receiving sets reveals that the ratio necessary to prevent interference varies widely with different sets. The limit of common commercial broadcast receivers was found to lie within the ratios of 1 to 10 and 10 to 1. Old receivers with vacuum tubes of impaired emission, changed tuning, etc., will undoubtedly be less selective than the new receiving sets studied. Many reports are now received from listeners complaining of cross-talk interference and a study of these cases reveals that the separation is often greater than that set out in Tables V and VI. It cannot be expected, however, that any plan of allocation will protect completely the poor grade of receivers and those in improper operating condition. Likewise, the full opportunities of allocation possible based on the better grade of receiving sets cannot be realized but an average must be used.

As the mileage separation becomes greater, a lower ratio is used between the desired and undesired signal, varying from 4.65 to 1 down to 0.85 to 1 on a sliding scale inversely with the mileage separation. This sliding scale is justified and represents the true condition on account of the fact that as the separation becomes greater, the consistency with which the interfering signal is received becomes less, due to the fact that interference is caused by fading signals which are intermittent.

The ratios used for 20-, 30-, and 40-kilocycle separation are based on a study of many receivers, with an endeavor made to protect a majority of the receivers located in the proper service areas of stations. A fixed ratio is used throughout with respect to the ratio used on the 10-kilocycle separation. All of the separations used in Tables V and VI are to protect the service areas of stations to the field intensity values given in Table III ninety per cent of the time under average conditions and average degree of propagation that is encountered throughout the United States. It is recognized that the absorption varies widely throughout different parts of the United States and that the table may be excessively conservative for certain areas of the country and give unnecessary protection in other areas. This is taken into consideration in studying any individual case.

TABLE V

Average Night Separation between Broadcast Stations Recommended by Engineering Division, Federal Radio Commission, Based on Frequency Maintenance of ±50 Cycles*

Power	Frequency Difference in Kilocycles	Local		Regional			High Power Regional		Clear			
		50	100	250	500	1 kw	2.5 kw	5 kw	5 kw	10 kw	25 kw	50 kw
Local[1] 50 w	0	140	200	—	—	—	—	—	—	—	—	—
	10	40	52	106	144	196	302	400	444	522	617	697
	20	18	22	39	52	71	107	147	162	197	232	257
	30	12	13	31	38	46	60	72	98	120	145	165
	40	9	10	28	35	43	57	69	95	117	142	162
100 w	0	200	200	—	—	—	—	—	—	—	—	—
	10	52	55	109	147	199	305	403	447	525	620	700
	20	22	25	42	55	74	110	150	165	200	235	260
	30	13	16	32	39	47	61	73	99	121	146	166
	40	10	13	29	36	44	58	70	96	118	143	163
Regional[2] 250 w	0	—	—	560	770	1050	—	—	—	—	—	—
	10	106	109	125	163	215	321	419	463	541	636	716
	20	39	42	58	71	90	126	166	181	216	251	281
	30	31	32	39	45	54	68	84	106	128	153	173
	40	28	29	33	36	48	62	74	100	122	147	167
500 w	0	—	—	770	770	1050	—	—	—	—	—	—
	10	144	147	163	170	222	328	426	470	548	643	723
	20	52	55	71	78	97	133	173	188	223	258	288
	30	38	39	45	52	60	74	91	112	134	159	179
	40	35	36	36	43	51	65	77	103	125	150	170
1 kw	0	—	—	1050	1050	1050	—	—	—	—	—	—
	10	196	199	215	222	230	336	434	478	556	651	731
	20	71	74	90	97	105	141	181	196	231	265	291
	30	46	47	54	60	67	82	99	119	141	166	186
	40	43	44	48	51	54	68	80	106	128	153	173
High Power[3] Regional 2.5 kw	0	—	—	—	—	—	1500	1950	—	—	—	—
	10	302	305	321	328	336	350	448	492	570	665	745
	20	107	110	126	133	141	155	195	210	245	280	305
	30	60	61	68	74	82	96	113	134	156	181	201
	40	57	58	62	65	68	75	87	113	135	160	180
5 kw	0	—	—	—	—	—	1950	1950	—	—	—	—
	10	400	403	419	426	434	448	460	504	582	677	757
	20	147	150	166	173	181	195	207	222	257	292	317
	30	72	73	84	91	99	113	125	151	175	198	218
	40	69	70	74	77	80	87	96	122	144	169	189
Clear[4] 5 kw	0	—	—	—	—	—	—	—	—	—	—	—
	10	444	447	463	470	478	492	504	530	608	703	783
	20	162	165	181	188	196	210	222	248	283	318	343
	30	98	99	106	112	119	134	151	158	180	205	225
	40	95	96	100	103	106	113	122	126	148	173	193
10 kw	0	—	—	—	—	—	—	—	—	—	—	—
	10	522	525	541	548	556	570	582	608	630	725	805
	20	197	200	216	223	231	245	257	283	305	340	365
	30	120	121	128	134	141	156	175	180	192	217	237
	40	117	118	122	125	128	135	144	148	154	179	199
25 kw	0	—	—	—	—	—	—	—	—	—	—	—
	10	617	620	636	643	651	665	677	703	725	750	830
	20	232	235	251	258	265	280	292	318	340	365	390
	30	145	146	153	159	166	181	198	205	217	232	252
	40	142	143	147	150	153	160	169	173	179	186	206
50 kw	0	—	—	—	—	—	—	—	—	—	—	—
	10	697	700	716	723	731	745	757	783	805	830	850
	20	257	260	281	288	291	305	317	343	365	390	410
	30	165	166	173	179	186	201	218	225	237	252	260
	40	162	163	167	170	173	180	189	193	199	206	210

* These separations are calculated to minimize objectionable interference in the good service areas of stations about 90 per cent of the time approximately as follows:
(1) 50-w to 100-w local channel, 2 millivolts, 7 to 10 miles.
(2) 250-w to 1000-w regional channel, 1 millivolt, 28 to 40 miles.
(3) 5-kw to 10-kw high power regional, 1 millivolt, 65 to 80 miles.
(4) 5-kw to 50-kw clear channel, 0.5 millivolt, 93 to 160 miles, and extent of intermittent service.

TABLE VI

AVERAGE DAY SEPARATION BETWEEN BROADCAST STATIONS RECOMMENDED BY ENGINEERING DIVISION, FEDERAL RADIO COMMISSION, BASED ON FREQUENCY MAINTENANCE OF ±50 CYCLES*

Power	Frequency Difference in Kilocycles	50	100	250	500	1 kw	2.5 kw	5 kw	5 kw	10 kw	25 kw	50 kw
		Local		Regional			High Power Regional		Clear			
Local[1]	0	95	120	155	190	240	285	315	315	380	450	520
	10	37	47	82	100	120	157	187	197	222	242	257
50 w	20	18	22	38	48	59	80	101	109	126	151	171
	30	12	15	31	38	46	60	72	98	120	145	165
	40	9	12	28	35	43	57	69	95	117	142	162
	0	120	120	155	190	240	285	315	315	380	450	520
	10	47	50	85	103	123	160	190	200	225	245	260
100 w	20	22	25	41	51	62	83	104	112	130	156	175
	30	15	16	32	39	47	61	73	99	122	146	166
	40	12	13	29	36	44	58	69	96	118	143	163
Regional[2]	0	155	155	250	260	310	380	430	430	490	580	660
	10	82	85	101	119	139	176	206	216	241	265	276
250 w	20	38	41	57	67	78	99	120	128	146	171	191
	30	31	32	39	46	54	68	80	106	128	153	173
	40	28	29	31	40	48	62	74	100	122	147	167
	0	190	190	260	260	310	380	430	430	490	580	660
	10	100	103	119	126	146	183	213	223	248	268	283
500 w	20	48	51	67	74	85	106	127	135	156	181	201
	30	38	39	46	51	59	73	85	111	133	158	178
	40	35	36	40	43	51	65	77	103	125	150	170
	0	240	240	310	310	310	380	430	430	490	580	660
	10	120	123	139	146	154	191	221	231	256	276	291
1 kw	20	59	62	78	85	93	114	135	145	167	192	212
	30	46	47	54	59	66	80	92	118	140	165	185
	40	43	44	48	51	54	68	80	106	128	153	173
High Power[3] Regional 2.5 kw	0	285	285	380	380	380	380	430	490	490	580	660
	10	157	160	176	183	191	205	235	245	270	290	310
	20	80	83	99	106	114	128	149	157	188	213	233
	30	60	61	68	73	80	92	104	130	152	177	197
	40	57	58	62	65	68	75	87	113	135	160	180
	0	315	315	430	430	430	430	430	560	560	580	660
	10	187	190	206	213	221	235	247	273	295	320	340
5 kw	20	101	104	120	127	135	149	161	187	209	234	254
	30	72	73	80	85	92	104	116	142	164	189	209
	40	69	69	74	77	80	87	95	121	143	168	188
Clear[4]	0	315	315	430	430	430	490	560	560	620	710	810
	10	197	200	216	223	231	245	273	283	308	338	350
5 kw	20	109	112	128	135	145	157	187	195	217	242	262
	30	98	99	106	111	118	130	142	147	169	194	214
	40	95	96	100	103	106	113	121	124	146	171	191
	0	380	380	490	490	490	490	560	620	620	710	810
	10	222	225	241	248	256	270	295	308	330	355	375
10 kw	20	126	130	146	156	167	188	209	217	232	270	277
	30	120	122	128	133	140	152	164	169	179	211	224
	40	117	118	122	125	128	135	143	146	151	176	196
	0	450	450	580	580	580	580	580	710	710	710	810
	10	242	245	265	268	276	290	320	338	355	375	395
25 kw	20	151	156	171	181	192	213	234	242	270	270	290
	30	145	146	153	158	165	177	189	194	211	212	231
	40	142	143	147	150	153	160	168	171	176	181	201
	0	520	520	660	660	660	660	660	810	810	810	810
	10	257	260	276	283	291	310	340	350	375	395	410
50 kw	20	171	175	191	201	212	233	254	262	277	290	315
	30	165	166	173	178	185	197	209	214	224	231	236
	40	162	163	167	170	173	180	188	191	196	201	205

* These separations are calculated to minimize objectionable interference in the good service areas of stations about 90 per cent of the time approximately as follows:

(1) 50-w to 250-w local channels, 2 millivolts, 7 to 15 miles.
(2) 250-w to 2.5-kw, regional channels, 1 millivolt, 26 to 55 miles.
(3) 5-kw to 10-kw, high power regional channels, 1 millivolt, 65 to 80 miles.
(4) 5-kw to 50-kw clear channels, 0.5 millivolt, 93 to 160 miles.

All of the average values herein set out must necessarily give way to actual measurements in any particular case. However, it does not follow that the average measurements do not represent a particular case, if one or two measurements taken at selected times do not agree. To show that these empirical and average standards of separation do not apply in any particular case, requires a series of measurements, extending over a period of time, which take in periods of known good propagation. Isolated measurements of field intensities of a station, particularly at distances greater than 50 to 100 miles from the station, are of little value when standing alone and do not represent the interference to be expected from that station.

The above empirical standards are based on the present design of antennas and average receivers. Improvements in either of these may permit of less geographical separation without increasing the interference and therefore permit a more economical usage of the present limited number of broadcast channels.

There is considerable research being carried on by laboratories and stations which will undoubtedly result in improvements in transmission and reception and make it possible to obtain greater use from the limited number of broadcast frequencies. The three outstanding methods by which such improvements may be accomplished are as follows:

1. Reduction in the sky-wave radiation.
2. Synchronization of stations on the same frequency with the same or different programs.
3. Improvements in receiving apparatus.

Considerable work is being done to develop an antenna that will discriminate against the sky-wave radiation. At the outset it may develop that this is a hopeless task on account of the fact that the radiation that gives rise to the nuisance radius of a station is at an angle of 15 to 20 degrees with the horizontal and therefore it would be impossible to discriminate between the ground wave and nuisance wave. A new type of antenna is being erected by two or three broadcast stations at the time of this writing which is known as the half-wave radiator. From a theoretical consideration of these structures it would appear that the high angle sky-wave radiation will be discriminated against and the ground wave increased which would increase the service radius by increasing the ground wave and distance to the fading area. Whether or not this will result in the reduction of the nuisance area of broadcast stations is problematical.

With the present type of antenna and 50-cycle frequency maintenance, the ratio of the service radius to the nuisance radius of a one-kilowatt station is 40 to 1000 or 1 to 25. This is the ratio in area of 1

to 625. Any development that will permit an increase in this ratio would be a great step forward. If this ratio could be increased to 1 to 1 (which is theoretically impossible, as the minimum signal determines the service area and the maximum the interference) there would be available facilities for many more stations. Synchronization of stations in its ideal consideration does not offer the advantages that are ideally conceivable if this ratio could be accomplished. A combination of the reduction of sky wave and synchronization will probably be the nearest approach to the ideal solution.

Development is being done on complex structures of a height not in excess of one-fourth wavelength to reduce the sky-wave radiation. The results reported and observed by the engineering division on these structures in the broadcast band have not been very satisfactory. The space and subject of this paper do not permit a further discussion on the need and advantages that may be accomplished from improved radiators.

Several tests have been conducted on the synchronization of broadcast stations to accomplish greater and improved service on a given channel without increasing the interference. These tests have been conducted mostly with stations employing five kilowatts or greater and so closely separated that it was necessary to use the same program at all times. Observations on these tests reveal that wherever the signal strength is of approximately the same intensity, objectionable distortion is encountered. If the terrain were entirely uniform between the stations, this area might be restricted to a narrow band, but as obstructions such as buildings, hills, etc., cast shadows of reduced field intensity in a direction opposite the station, and on the approach side of such obstructions there is no reduction in the field intensity, these areas are approximately equal in intensity and may be widely scattered and may be near one of the stations. Another system of synchronization that is being considered and in operation in one case, consists of a large station and a small so-called booster station located in a center of population where the signal from the larger dominant station is not sufficient to render good service. The power of the so-called booster station is restricted to just sufficient to cover satisfactorily the center of population, and accordingly does not give rise to the large rural areas of approximately equal signal intensity and the resultant interference in these areas.

Improvements in the selectivity of receiving sets will permit of placing stations on adjacent frequencies at less mileage separation. Certain types of receiving circuits are inherently more selective than other types. The Commission has no control over receiving sets and there-

fore the empirical standards set out above are made considering the receivers now in use. There is one type of receiver being sold rather extensively at the present time that is considerably inferior to what is considered the average receiver on which the above standards are based. All such receivers may experience difficulty in separating stations that otherwise could be received with satisfactory reception.

While broadcasting is ten years old, the accumulation of accurate data concerning its greatest problem, allocation, is very small. Many experiments need to be started and many started need to be completed. The most efficient use possible must be made of all facilities and it is only by the use of more accurate data which must first be obtained, that it will be possible to meet this requirement.

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ACOUSTICAL AND ELECTRICAL POWER REQUIREMENTS FOR ELECTRIC CARILLONS*

By

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Summary—*The importance is shown of making noise level measurements in order to determine the acoustical or electrical power necessary to blanket any given area with satisfactory music. Measurements were made on the bells of the Valley Forge carillon, over a wide area using a sound meter and a local variable noise making machine. These data gave the necessary relations between noise level and satisfactory music and were used to calculate the acoustical and electrical power requirements. Two methods of making noise level measurements particularly suitable for acoustical surveys of this kind are mentioned. With the measured and calculated data, curves have been drawn up which permit rapid calculation of the audio power requirements for any given noise level and for various coverages.*

THE value of the acoustical power necessary to give pleasing sound and of the required ratio of the electrical power to the acoustical power are of prime importance in determining whether a large outdoor loud speaker installation will give satisfactory performance. An answer to this question has become vital in the installation of electric carillons.

A great deal of work has been done on the tone quality of these electrical bells to make the fundamentals and partials similar to that of a high quality set of true bells. As a next step, it was necessary to produce satisfactory volume over whatever area the installation is required to cover. Since the electrical installation is not limited in its acoustical output in the same way as a mechanical musical instrument, this may mean that a great deal more acoustical power will be radiated in certain cases than would come even from a large set of bells.

In determining the acoustical power to be radiated by the bells, the prime considerations are the distance to be covered and the surrounding noise level to be overcome. A number of bell installations have been made in this country and abroad where it has been difficult to hear the bells with pleasing results because of a high surrounding noise level. Sometimes the towers were built too high and the sound was attenuated sufficiently to make listening difficult in the normal noise level even for listeners who are close to the tower. Good examples of the difficulties encountered are given by several installations in large

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cities, where the pleasure that should be obtained from the very fine set of bells is materially lessened by the difficulty of listening to the rather weak sound with the high surrounding noise level due to a large amount of automobile traffic and other miscellaneous noises.

It is the purpose of this paper to determine first, by experiment, the acoustical power radiated by a true set of bells; second, the sound

Fig. 1—Sound meter showing acoustical calibrator.

which must be produced by these bells to give pleasing music in the presence of any specified noise level; and third, the electrical power requirements which are necessary to give this sound level at any specified distance from the bells and in the presence of any measured noise. In order to put the final object of the experiment in practical form, the results of these data have been drawn up on easily handled curves which should indicate rapidly the audio power requirements, and sim-

ple portable apparatus has been developed for making the necessary noise measurements.

Procedure

It was necessary first to locate a set of bells which would give satisfactory data for the calculations. It was also evident that a fairly quiet location would be best so that a wider range of noise could be studied. There are several very good carillons in and around Philadelphia, but the best location for test purposes was found at Valley Forge Park, Valley Forge, Pennsylvania.

There are thirty-six bells at the present time in the carillon at Valley Forge, ranging from A sharp below middle C to A sharp three octaves above. They were made by the Meneely Bell Company of Troy, New York. The bells sound very well. In the lower register they are somewhat muffled and the upper bells are a little uneven in volume, which is typical of almost any set of bells. A list of the bells with their weight is included in the appendix to this paper and is presented to indicate the approximate type.

The bells were mounted in an open structure tower with the heaviest bell about twenty feet from the ground, and the highest pitched bell about forty feet. The tower is located on the top of a small hill, in a grove of trees. The Valley Forge chapel stands about twenty feet away and partially blocks the sound in one direction.

Measuring Equipment

A portable sound measuring meter[1] was used to determine the intensity of the bells and the surrounding noise. (Figs. 1 and 2.)

This meter is of the type known as RCA Victor TMV-26, and is similar in its general principle of operation to some which have already been described and used for noise surveys and the study of machinery noise.[2]

It consists of a permanent magnet ribbon microphone to pick up the sound followed by sufficient amplification to give a reasonable deflection for low intensity sounds on a vacuum tube voltmeter. The over-all frequency response is adjusted so as to correspond with the pure tone sensitivity of the ear as determined by Kingsbury.[3] Since the sensitivity of the ear as a function of frequency depends on the intensity of the sound, two positions are made available—one corresponding to a sound intensity approximately 70 db above the threshold of audi-

[1] This sound meter was designed by Frank Massa of RCA Victor Company, Inc.

[2] For good review and bibliography *see* E. E. Free, *Jour. Acous. Soc. of Amer.* **2**, 18, 1931.

[3] B. A. Kingsbury, *Phys. Rev.*, **29**, 588, 1927.

bility at 1000 cycles, and the other approximately 40 db above this threshold. The latter is used when weak sounds are encountered, and the former for intense sounds. The vacuum tube voltmeter is so constructed that its response follows the square law over the useful range

Fig. 2—Sound meter assembled showing wind screen.

so that the energy of the composite sound, weighted in accordance with the pure tone frequency response at either 70 db or 40 db, is what is measured.

At its maximum sensitivity, the instrument can measure sound approximately 20 db above the threshold of audibility, and sufficient at-

tenuation is supplied so that any louder sounds which are encountered can be determined. A schematic diagram of the apparatus is shown in Fig. 3. The output of the microphone is fed to a two-stage amplifier and then to an attenuator which is calibrated in decibels. This is followed by another tube and a switching arrangement which permits transfer from the 40 db to 70 db level. This is followed by another volume adjustment which permits the sensitivity of the whole system to be adjusted to some predetermined value as we shall describe. The final stage is followed by the vacuum tube detector and a switching arrangement which permits the amplifier output to be carried to some external bind-

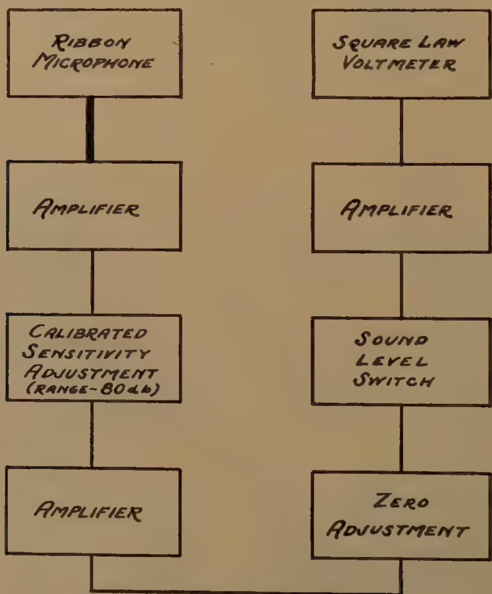

Fig. 3—Schematic diagram of sound meter:

ing posts instead of to the detector for frequency analysis of the sound impressed on the microphone, if such is desired.

In order to calibrate the instrument, a standard sound is supplied which is placed at a predetermined distance in front of the microphone. This sound is generated by a pitch pipe actuated by constant air pressure. The constant air pressure is obtained by having a relatively heavy piston drop under the force of gravity in a cylinder in which the pitch pipe is the only outlet. The pressure supplied to the pitch pipe is thus always equal to the superficial weight of the piston since its weight is made sufficient so that friction encountered in falling can be neglected.

The process of using the sound meter is as follows:

The acoustic calibrator is attached to the microphone in its specified position and the attenuator is adjusted until some convenient reading is obtained on the vacuum tube voltmeter. The sound level supplied by the pitch pipe at its frequency has been determined by a laboratory experiment. The zero adjustment of the amplifier is turned until the reading of the attenuator, plus that of the vacuum tube volt-

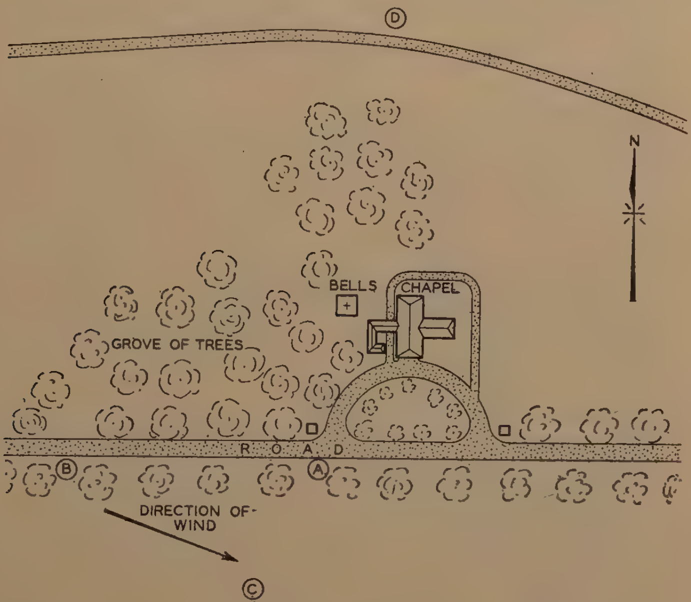

Fig. 4—Plan of location where measurements were made.

From bell tower	From bell tower
Distance to A—185 feet	Distance to C—370 feet
Distance to B—370 feet	Distance to D—345 feet

meter, equals the sound intensity which is supplied by the acoustic calibrator. The calibrator is then removed from the microphone and the equipment is ready for use.

In making sound measurements, the attenuator is turned to some position so that the vacuum tube voltmeter is at a position approximately in the middle of the scale and readings of the vacuum tube voltmeter are made and added to that of the attenuator setting to determine the loudness of the sound.

Tests

The sound measuring meter was taken to Valley Forge Park, where four locations were chosen to make measurements. These positions are

shown in Fig. 4. At each of these points the maximum intensity of bells in the lower register, middle register, and upper register was measured. Average and maximum readings during the playing of a short tune were noted. The noise level was also determined at each point. At posi-

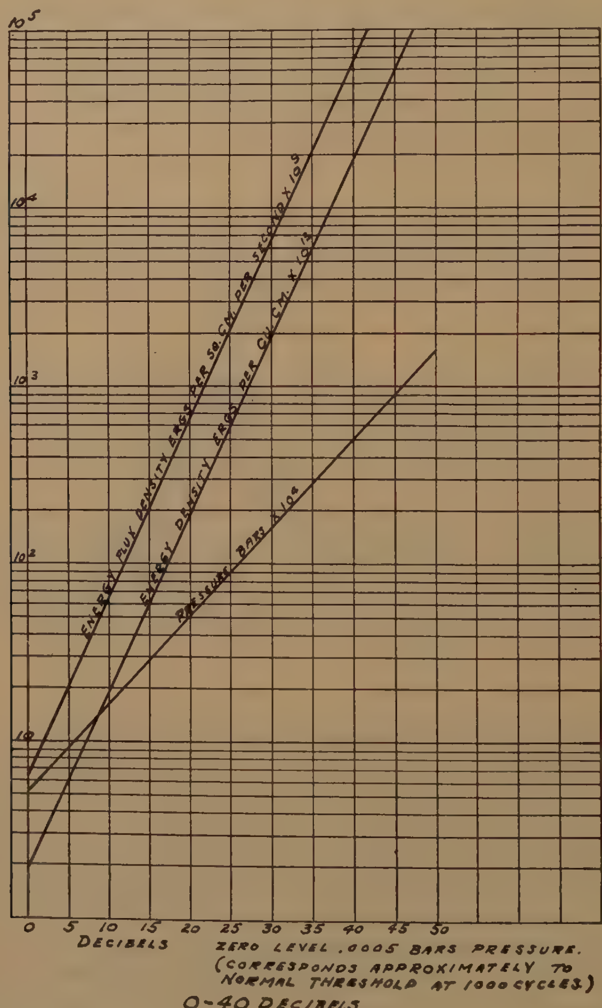

Fig. 5.

tion *D*, by means of an auxiliary variable noise making machine, measurements were made to determine the highest noise level at which the music produced by the bells could be called satisfactory. The variable noise making machine was the motor of a Model A Ford. The observer,

as well as the microphone of the noise measuring meter, was stationed about three feet from the source of the noise.

After completion of these tests, an audibility test was made on the bells at various distances up to one and one-half miles. At distances of

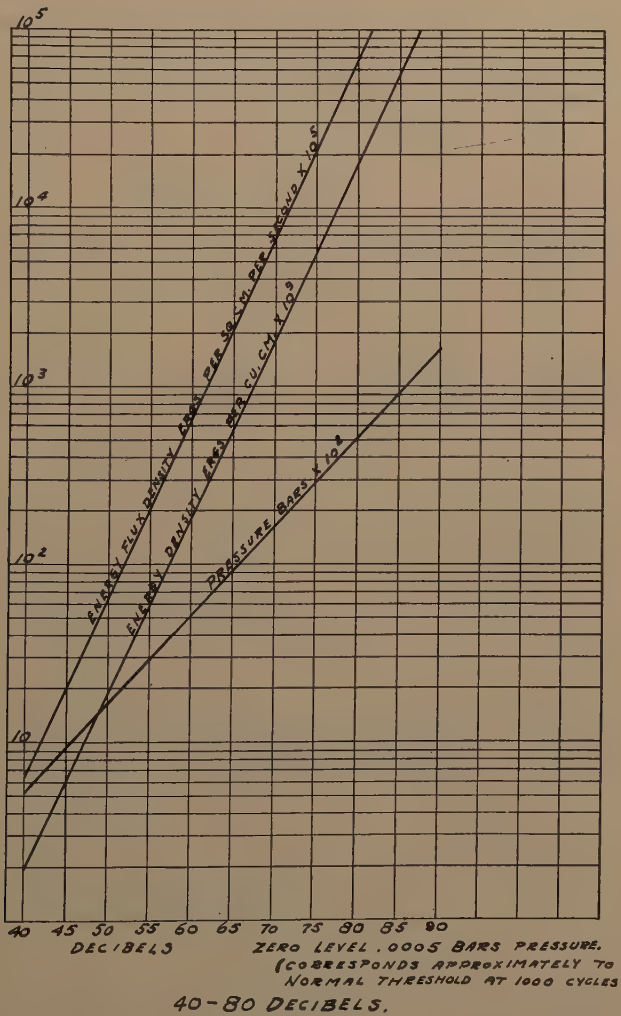

Fig. 6.

one-quarter mile, one-half mile, one mile and so on, data were taken as to the satisfactory audibility of the bells. The intensity of the noise making machine was varied at each one of the points until the bells were just satisfactory, and then just inaudible, data being recorded of

said noise level, and condition of audibility. Owing to the fact that the sound produced by the bells approached that of the general noise level,

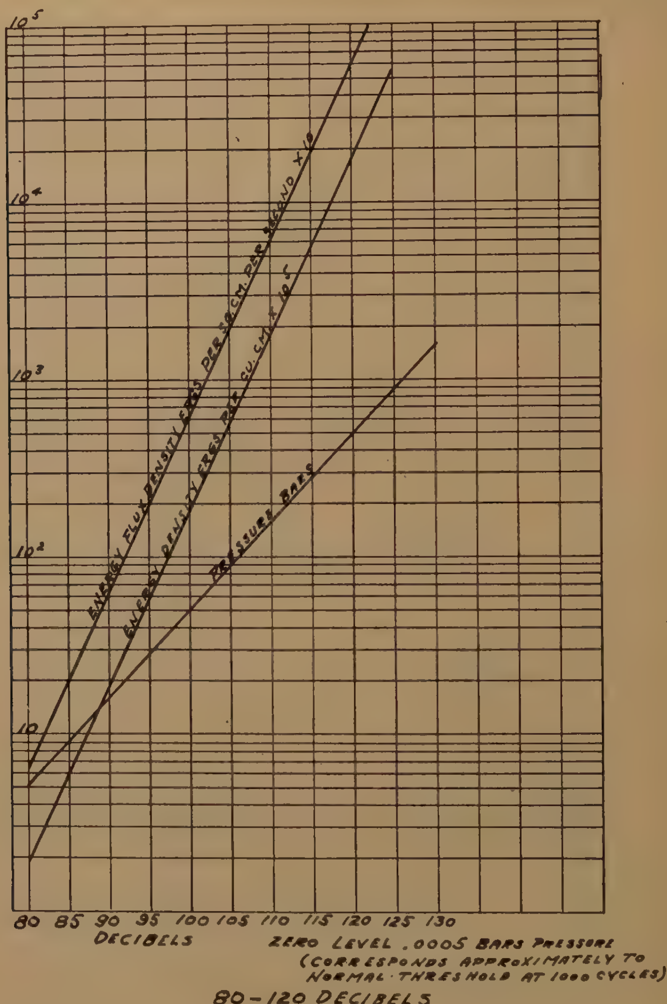

Fig. 7.

Figs. 5, 6, 7—Conversion curves from decibels above zero intensity level corresponding to 0.0005 bar, to sound pressure, energy density, and energy flux density. The zero level corresponds approximately to normal threshold of audibility at 1000 cycles.

direct measurement of the bell sound intensity was impossible at the greater distances.

Data

After the completion of the above tests, the data were tabulated as shown in Table I. The first two columns give the position, and the register of the bells tested. The third column is the direct reading of the sound meter made in the field.

TABLE I

Sound Developed by the Bells at Various Positions and Radiated Acoustical Power

Position	Bell	Intensity in decibels	Sound pressure in bars	Energy (flux density ergs)	Watts
A	Low	62	0.65	0.01	0.2
	High	72	2.00	0.10	2.0
(185 feet)	Middle	67	1.20	0.03	0.65
	Hour	65–66	0.95	0.02	0.45
B	Low	*60	0.50	0.006	0.50
	High	53	0.25	0.0012	0.10
(370 feet)	Middle	59	0.60	0.005	0.40
	Tune	60–66	0.60	0.025	0.80
C	Low	56	0.30	0.002	0.20
	High	55	0.30	0.002	0.16
(370 feet)	Middle	63	0.70	0.0012	1.0
	Tune	54–65	0.25–0.90	0.0015–.02	0.12–1.6
D	Low	61	0.60	0.008	0.55
	High	56	0.30	0.0025	0.17
(345 feet)	Middle	61½	0.60	0.009	0.62
	Middle	64	0.80	0.016	1.10
	Hour	56	0.30	0.025	0.17
	Tune	56–65	0.30–0.90	0.025–0.02	0.17–1.4
Noise Level					
(Objectionable)		64	0.9		
Idling Motor		56	0.30		

* Poor reading because of passing truck.

As the measurements were taken in decibels above a specified zero level, it is necessary, before making calculations, to convert to sound energy flux density or pressure. Columns four and five, taken from Figs. 5, 6, or 7, show this conversion. Figs. 5 to 7 show the relations between decibels above zero level of 0.0005 bar, sound pressure, energy density, and energy flux density and allow any one of these quantities to be determined in terms of the others.

The last column in Table I is acoustical watts radiated by the bells which has been determined by using information in the fifth column and is based on the assumption that the energy radiated by the bells is almost the same in all directions in a hemisphere, leading to the equation

$$\text{Acoustical Watts} = \frac{R^2 \times 2\pi \times \text{Energy Flux Density}}{10^7} \tag{1}$$

in which R is distance in centimeters between the bell and the point of observation, and the energy flux density is measured in cgs units.

Table II gives a résumé of the data, showing the audibility of the bells at different distances, and various noise levels. The average noise

TABLE II

RELATIONS BETWEEN DISTANCE, NOISE LEVEL, AND AUDIBILITY

Position	Distance	Noise level	Audibility
E	½ mile	30 to 40 db	Very good
E	½ mile	56 db	Almost satisfactory
E	½ mile	64 db	Inaudible
F	1 mile	30 to 40 db	Good
F	1 mile	56 db	Almost inaudible
G	1⅜ mile	30 to 40 db	Just audible
G	1⅜ mile	56 db	Inaudible
D	345 feet	64 db	Highest noise level which is satisfactory

level created by various sounds such as the wind, leaves, birds, insects, and rumble of machines in the distance was about 30–40 db at Valley Forge. Under the conditions of measurement, this was therefore the lowest noise level at which the sound from the bells could be studied. A Ford motor idling at three feet caused 56 db noise. When the motor was running about half speed the noise created was 64 db.

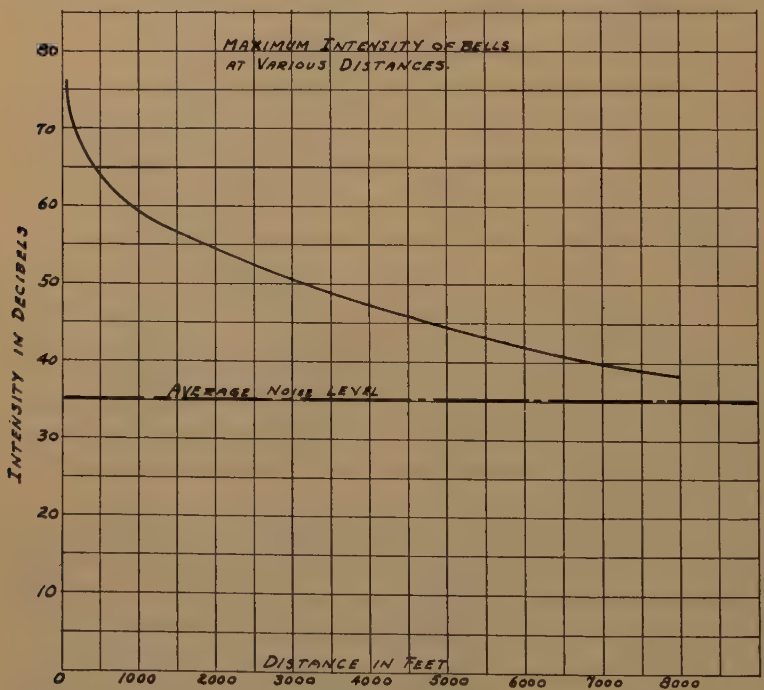

Fig. 8—Maximum sound developed by the bells at various distances.

CALCULATIONS

We must now determine the sound which must be produced by the bells or electric carillons in order to overcome various noise levels which

may be present and give audible and pleasant musical reproduction in spite of this noise level. There were no data available on this subject so that the series of tests which were made at Valley Forge were used as the basis for this computation. A comparison of columns 3 and 4 in Table II gives the relation, as determined experimentally, between the audibility of the bells and the noise level. At distances remote from the

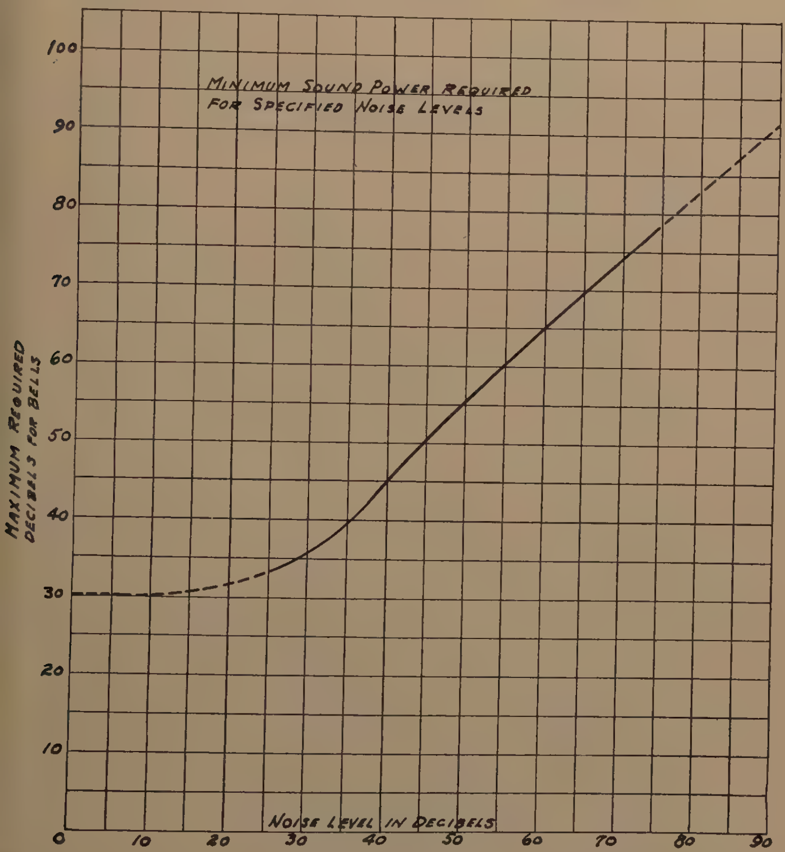

Fig. 9—Maximum sound power required for specified noise levels.

ells, as has been explained previously, a measurement of the intensity roduced by the bells was impossible, due to the fact that the noise evel was being approached. In order to use the data which were taken t these points, the assumption has been made that the inverse distance aw holds for the pressure produced by the sound wave. While this as-umption cannot be entirely correct, evidently due to the rather rolling ontour of the land over which the sound had to pass, it seems to be

the most logical one to make in order to determine approximately the minimum intensity of sound which will give satisfactory music. Since we are ultimately interested in determining the power which the electrical amplifier must handle in order to give satisfactory sound, we have expressed these results in terms of the maximum intensity produced by the bells.

In Fig. 8 we show a curve taken from the measured data and for the more distant points assuming the inverse square law, giving the maxi-

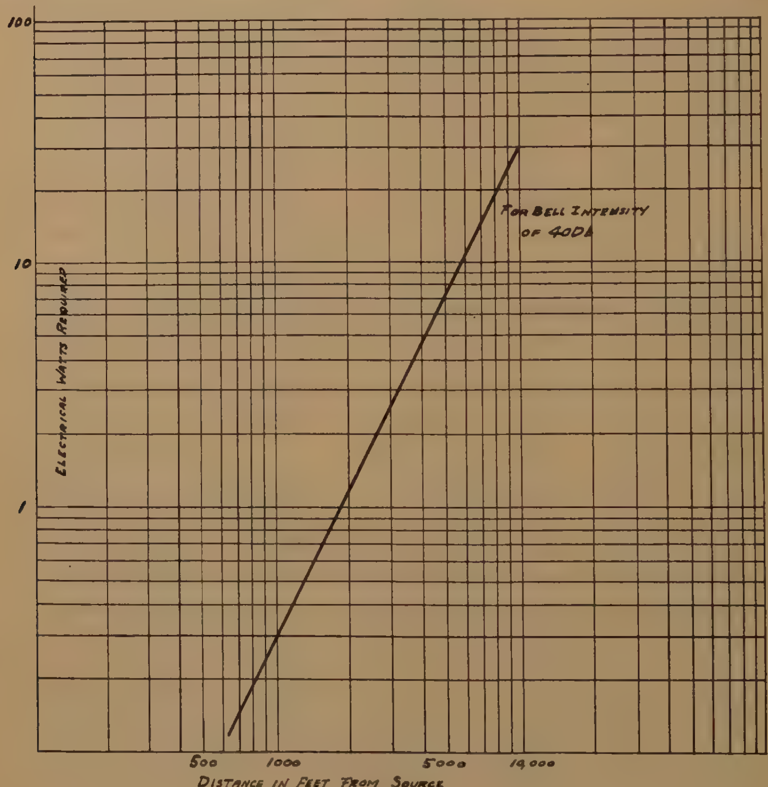

Fig. 10.

mum sound intensity produced by the bells at various distances. Using this curve and the data in Table II, the desired relation between noise level and necessary sound intensity to be produced by the bells has been obtained. (Fig. 9.)

Assuming that the bells radiate uniformly into a hemisphere, the calculations of the acoustical power which is necessary to supply this sound intensity at a specified distance is a simple matter with the aid of equation (1) and Figs. 5, 6, and 7.

Measurements which have been made on large high powered sound projectors for outside use indicate that an effective efficiency over a circular region of 12.5 per cent may be obtained. This takes into account the directional characteristics of the loud speakers. The power which the electrical amplifier must handle to produce the requisite sound in-

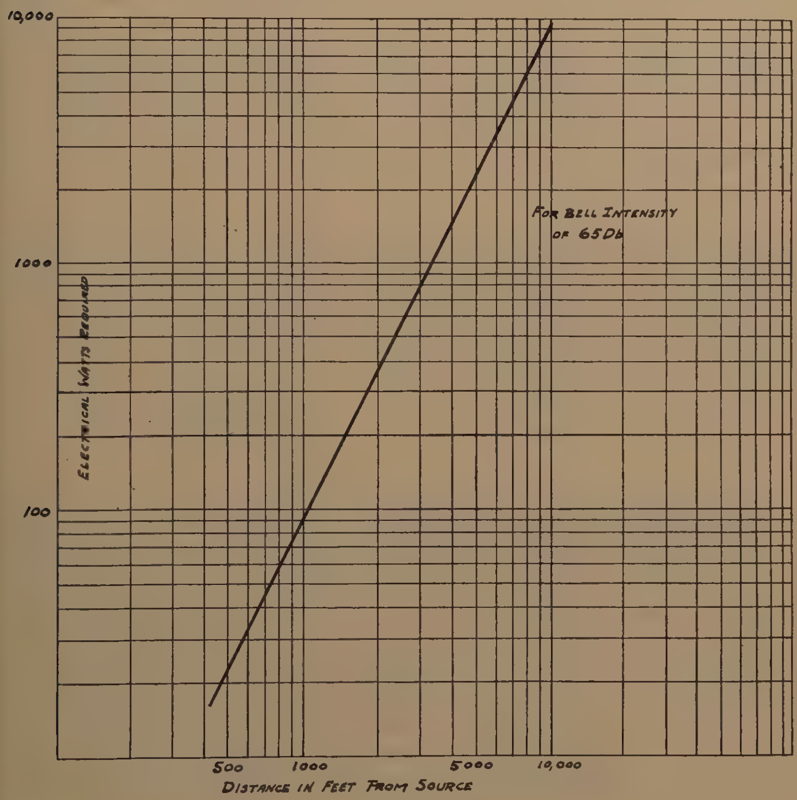

Fig. 11.

tensity is equal to the acoustical power, as computed, divided by this efficiency.

As an example of the electrical power which must be handled in order to supply satisfactory music at various distances and to overcome some common noise levels, some results have been computed using the above methods and are shown in Figs. 10, 11, and 12. An idea of the noise represented by these levels in comparison with some common noises may be obtained by reference to Table II in the appendix.

Substitute Noise Measuring Devices

At times the accuracy of sound measurement, which is obtainable with the sound meter, is not required, and cheaper and simpler equipment can be used for making the preliminary noise surveys. A system using a simple tuning fork has been suggested by A. H. Davis[4] and can

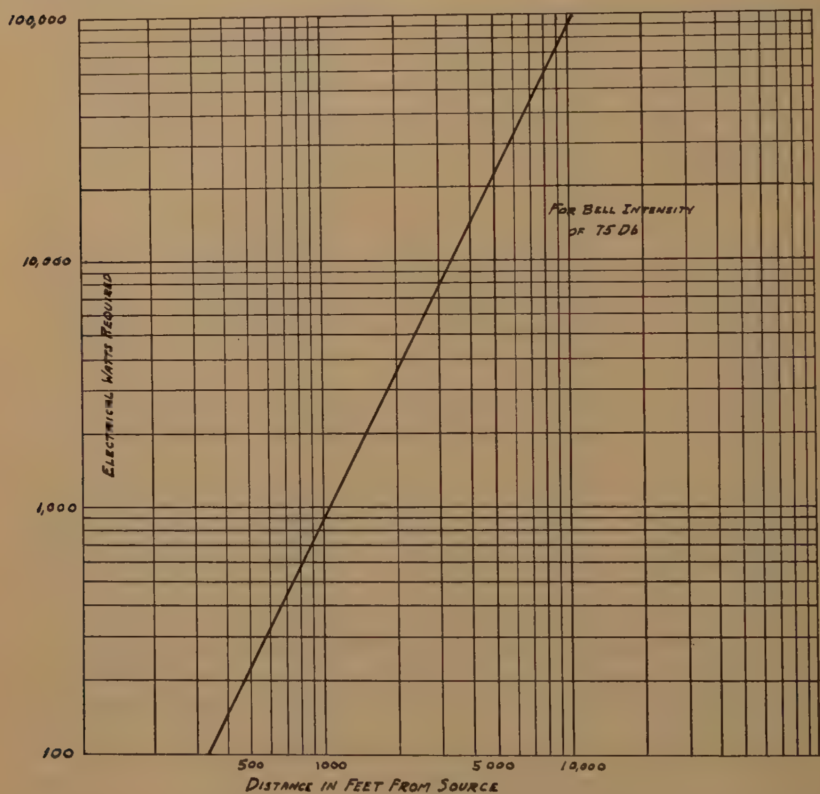

Fig. 12.

Figs. 10, 11, 12—Relations between maximum sound intensity to be developed by the bells at a specified location, distance from the source and electrical power required.

be used to obtain a good approximate determination of the sound level. If the tuning fork has been carefully calibrated by comparison with the sound measuring meter, it can be used with some degree of success.

When a tuning fork is struck with a mechanical striking mechanism, which insures a uniform striking blow, the sound energy emitted by the

[4] A. H. Davis, *Nature*, **125**, 48, 1930.
E. E. Free, *Jour. Acous. Soc. of Amer.*, **2**, 18, 1931.

fork dies away at a logarithmic rate. The length of time that its vibrations are audible after striking will depend, if everything else is fixed, only on the surrounding noise level. This time is a measure of the deafening effect caused by the noise. Since there is an approximately constant difference of 15 decibels between the noise level and the minimum sound level in the middle range which can be heard in the presence of the noise, the tuning fork can be used to measure noise level.[5]

Assume that the fork is struck with the same intensity and held at some fixed distance from the ear at all times so that a sound intensity I_0 is generated at the ear. The intensity due to the fork at any subsequent time may be expressed as:

$$I = I_0 \times 10^{-.1\delta t}. \qquad (2)$$

Where I_0 is the intensity immediately after striking, δ is a decay constant in decibels per second, and t is the time after striking in seconds. In order to express sound level in the usual manner in decibels with respect to a zero level close to threshold, divide both sides of the equation by the zero level intensity I_T, then take the logarithm to the base 10 and multiply by 10

$$10 \text{ Log} \frac{I}{I_T} = 10 \text{ Log} \frac{I_0}{I_T} - \delta t \qquad (3)$$

Loudness level in decibels above threshold = initial loudness level in decibels $- \delta t$ (3a). In a perfectly quiet room the sound from the fork will die away to inaudibility at the threshold of hearing for the fork frequency. If the noise is present, the ear of the listener will be effectively deafened and the sound will become inaudible in a shorter time. The loudness level of the sound supplied by the fork at cut-off will be approximately the noise level minus 15 decibels, for the noises near the middle of the sound intensity range.

Using the equation which has been developed for the loudness of sound supplied by the fork

$$\text{Noise level} = \text{initial fork loudness level} - \delta t + 15 \qquad (4)$$

when all quantities are expressed in decibels.

In order to determine the noise level, therefore, the initial fork loudness level, the decay factor and the time of audibility must be known. Time of audibility is easily determined with a stop watch. Several forks of a series of frequencies should be used so that peculiarities in the noise spectrum will not destroy the accuracy of the results.

[5] R. H. Galt, Report of N. Y. C. Noise Abatement Commission, 1930, page 146.
R. S. Tucker, Report of N. Y. C. Noise Abatement Commission, 1930, page 157.

The forks used in outdoor measurements are C-256 cycles and C-512 cycles. They have mechanical strikes which permit a constant initial intensity. The decay of the forks has been accurately determined in the acoustic laboratory, by holding the fork a constant distance in front of the microphone of the sound measuring meter, and noting meter readings at specified time intervals. The decay characteristic of a C-512 cycle fork is shown in Fig. 13. This curve gives the value of δ for (4) as approximately 0.54 decibel per second.

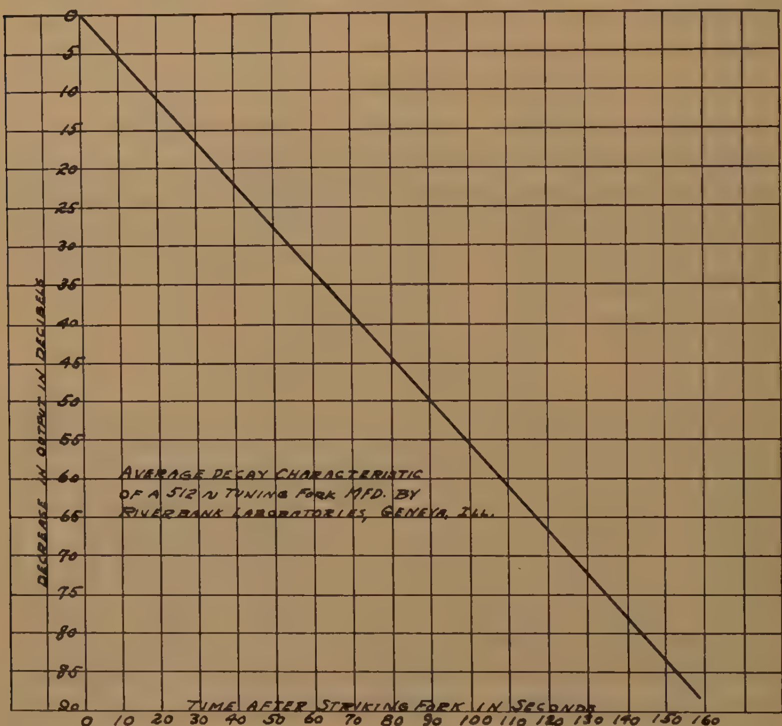

Fig. 13—Average measured decay characteristic of a 512-cycle tuning fork.

The initial loudness produced by the fork at the ear must be obtained by trial and computation. This value, of course, will vary somewhat with individuals due to differences in ear sensitivity, although for normal persons under normal conditions the ear sensitivity is constant enough. The sound measuring meter is used in a quiet room to calibrate the fork for any specific person, in conjunction with methods for generating various noises. The noises are calibrated in intensity and the tuning fork is struck and timed for inaudibility. Using several different values of intensity of noise, and having measured these by the sound

meter, a value of the initial fork loudness level for that person may be computed. Several such tests and curves should be made and an average curve struck for each individual. A curve for two individuals is shown in Fig. 14.

Care should be taken in using the fork to see that it is held the same distance from the ear for all tests. The fork should also be waved back and forth in front of the ear, because the ear becomes "paralyzed" if the fork is held in a stationary position. When making measurements,

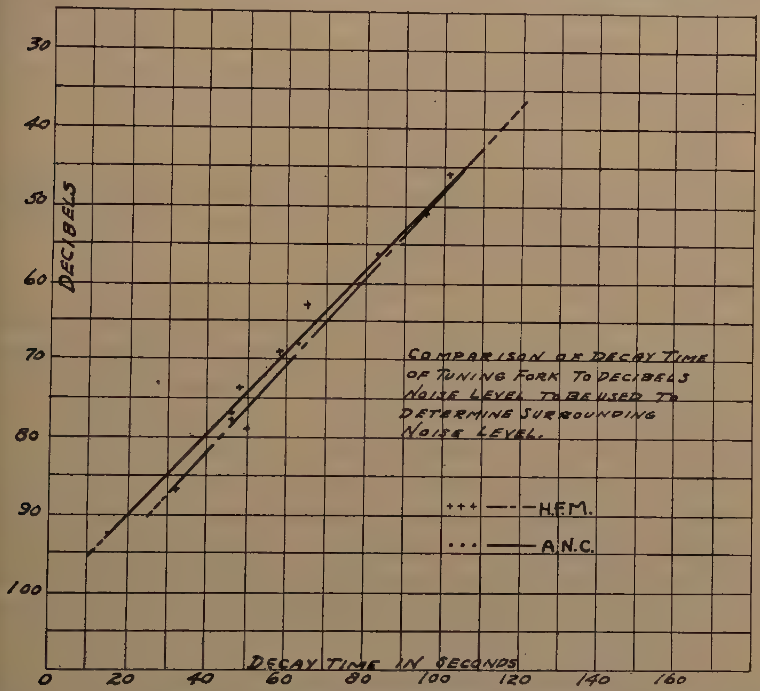

Fig. 14—Relations between noise level and the time of audibility of tuning forks for two observers.

several tests should be made at each location and the average taken because of variations caused by wind and various passing elements.

In order to illustrate the use of the tuning fork method of noise measurement and the curves which are used, the following example is given:

Suppose it is desired to make an installation of electric bells, which are to be heard satisfactorily over an area described by a circle whose radius is one thousand feet. The information required is the necessary electrical power input to the speaker.

At several points on the circumference of this circle, tests are made

with the tuning fork, under normal conditions of noise. The tuning fork is struck by the mechanical device and the time necessary for its sound to die away to inaudibility is determined by a stop watch. This test should be repeated several times and the average time recorded. Suppose the average time is seventy-eight seconds. From the curve in Fig. 14, it is noted that the noise level for this time is 60 decibels. Referring to the curve in Fig. 9, we find that for a noise level of 60 decibels, the sound level for satisfactory audibility is of the order of 65 decibels. We take this value and go to one of the curves of comparison of noise level, distance, and electrical watts input. For a level of 65 decibels, we shall use the curve in Fig. 11. The distance from the source is 1000 feet, and the electrical power input required is 90 watts.

Results

With the two methods described for the measuring of noise level and the calculations and curves submitted in this paper, the required electrical power can be easily computed.

Curves 10, 11, and 12 in this paper have dealt with four directional loud speakers covering a circular area. Cases may arise in which only a semicircular area should be blanketed, in which case only two speakers would be used. Only half the power would be required for this two-speaker installation. Other special cases which arise may be handled with similar procedure to that used for the four-speaker installation.

Outdoor installations of any kind should be carefully surveyed in this manner to determine the actual requirements to give satisfactory audible results. Of course, this procedure is not limited by any means to outdoor tests alone. With certain modifications of computation this type of acoustical survey may be used quite readily for the engineering of indoor loud speaker installations.

The wide variations of electrical and acoustical power required, as shown by our data, with changes in noise level and area to be covered by the sound, shows the necessity of a careful survey of the area and location to be covered by the installation.

A statement of the acoustical power radiated by a set of bells or electric carillons is a fundamental characterization. Very little information, however, as to the performance to be expected in a specific location is given unless the noise conditions of the location where it is to be installed are also known.

Acknowledgment

The authors of this paper wish to thank Dr. Burke, the Rector of the Valley Forge chapel, whose coöperation in the making of the tests on the intensity of the bells was greatly appreciated.

Appendix

In order to show the type of bells on which these tests have been based, the first table of Appendix I lists the bells at Valley Forge with their respective tones and weights.

APPENDIX I

Data on Bells of the Valley Forge Carillon

Number	Tone	Weight in Pounds
1	A sharp	8000
2	B	6400
3	C	5600
*4	C sharp	4800
5	D	4000
6	D sharp	3200
7	E	2800
8	F	2400
9	F sharp	2000
10	G	1600
11	G sharp	1300
12	A	1100
13	A sharp	1000
14	B	800
15	C	700
16	C sharp	600
17	D	500
18	D sharp	400
19	E	350
20	F	325
21	F sharp	275
22	G	225
23	G sharp	200
24	A	175
25	A sharp	150
26	B	125
27	C	115
28	C sharp	100
29	D	90
30	D sharp	80
31	E	72
32	F	65
33	F sharp	56
34	G	50
35	G sharp	42
36	A	35
37	A sharp	30

* No. 4 bell missing—Total weight, 49,760 pounds.

Appendix II is a list of common noises with their respective intensities in decibels taken from the report of the New York Noise Commission.

By reference to the appendix and Fig. 9, a preliminary estimate of the power required to overcome certain common noises may be obtained.

APPENDIX II

COMPARATIVE NOISE LEVELS—*VARIOUS TYPES OF NOISE AND ITS INTENSITY IN DECIBELS

Source of Sound	Decibels
Just Audible Level	0
Rustle of Leaves in Gentle Breeze	10
Average Whisper	23
Average Residence	33
Average Business Office	50
Passenger Automobile (15 to 50 feet)	65
Motor Trucks (15 to 50 feet)	75
Heavy Street Traffic	82
Subway Noise	96
Loudest Automobile Horn	106
Motor and Propeller of Plane (18 feet)	115
Level of Painful Noise	130
Other Sources	
Quietest Residence Measured	24
Country Residence	27
Average Residence	31
Quietest Non-Residential Measured	34
Average of 6 Factory Locations	68
Some Factories	85
Very Quiet Radio in Home	40
Very Loud Radio in Home	80

* Taken from "City Noise" by Noise Abatement Commission, New York City.

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MICA CONDENSERS IN HIGH-FREQUENCY CIRCUITS*

By
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Summary—*Mica condensers have a variety of uses in high-frequency circuits. They are called upon to store electrical energy, block direct current, by-pass high-frequency current, etc. Each of these functions is discussed in detail. Conventional construction of mica condensers is described. A method of arriving at satisfactory ratings is shown. The following examples are worked out:*

1. Calculation of requirements for tank condenser bank.

2. Calculation of rating of a given condenser.

3. Calculation and choice of a proper bank of condensers for a tank circuit with 100 per cent modulation.

MICA condensers are widely used in construction of high-frequency apparatus. Wherever either a small size for a relatively high capacity is desired, or a condenser with low power factor, or a condenser for very high operating voltage is needed, or all of these requirements together are to be satisfied, mica condensers are first to be considered. They are used extensively in radio transmitters, also in high-frequency furnaces, carrier current communication systems, transoceanic telephone systems, etc. In radio receivers their most important application is for tuning of the intermediate stages of superheterodyne sets. With the advent of the thyratron and the general invasion of the industrial field by the thermionic devices, the use of mica condensers is increasing every day. The purpose of this paper is to outline the performance of mica condensers in high-frequency, high voltage circuits and to describe their construction, manufacture, uses and selection in connection with design of high-frequency apparatus.

There are several distinct functions that a mica condenser in a high-frequency circuit may be called upon to perform. The first, and by far the most important one, is to condense or to store electrical energy in an electric field. Such is a function of the tank condenser in an oscillating circuit, an antenna coupling condenser, also of a carrier current coupling condenser. The second function is to block direct current from flowing into a circuit while allowing passage of alternating current. The third function is to prevent alternating current from flowing through resistances, meters, and other apparatus and by-passing

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it around them. The fourth is to reduce the ripple of pulsating current, such as in rectifier networks.

All of these functions will be understood more clearly after going into the construction of a mica condenser somewhat in detail.

The main material entering into the construction of mica condensers, as the name implies, is mica. The word mica is used as a name for a group of minerals which are characterized by a laminated structure, resistance to high temperatures, and relatively high transparency. All this group consists of a combination of aluminum silicate with either some alkali or iron and magnesium. Muscovite and paragonite are examples of alkaline mica, while biotite is an example of ferromagnesian mica.

Mica is a mineral and is found in many different countries. Until recently, the general opinion held that only Indian mica from the Bengal province was suitable for the manufacture of mica condensers. Recently published results of tests made by the Bureau of Standards prove conclusively that there are many grades of domestic mica which are as good and even slightly better for the purpose. The raw mica, in the form of flat pieces with irregular edges, is split into thin sheets and cut to size. Both of these operations are still performed by hand, as all the efforts to devise automatic machinery for this purpose have failed so far.

A high voltage mica condenser consists of a combination of individual condensers called sections. These sections are usually connected in series, forming stacks. Sometimes several stacks are connected in parallel. The stacks are placed in cases and the cases are filled with compound. A case usually has two or more terminals. Sometimes the sides of the case are used as terminals and the body of the case is made of some insulating material.

A section is made of a definite number of sheets of mica and a number of metal foils. Lead foil is used most generally, except on shortwave condensers where copper is found more suitable. The usual form and size of mica is a rectangle around 1.5 by 1.5 inches and is seldom more than 2 by 3 inches; thicknesses from 0.001 up to 0.004 inch are used. The foil size is correspondingly smaller to allow for at least one-eighth of an inch margin.

The section is put together by placing mica and foil one on top of the other, carefully observing the margins. All odd foils are allowed to protrude beyond the edge of one side of the mica rectangle while all even foils protrude on the opposite side of the mica sheet. All odd foils are then soldered together and the same is done to the even foils. To hold the section together while stacking, the mica sheets are dipped in

paraffin during the assembly. To make a stack, several sections are soldered together. Micanite separators are used to keep sections at a distance each from the other. After the stacks are adjusted for correct capacity with due allowances for changes likely to occur during the treating process, they are placed in cases and clamped. The paraffin impregnation under vacuum is the next operation. Then the excess paraffin is poured out, the cases are cooled and filled with a suitable filling compound, after which the covers and name plates are installed.

There are several electrical tests in between these manufacturing operations. Sections are tested at a voltage somewhat below the breakdown voltage of the mica. This throws out all questionable sections. The stacks are again tested at a voltage much higher than any peak voltage that may be encountered in practice.

The above two tests are made at a frequency of sixty cycles per second. After a condenser is completed, it is checked on high voltage and then subjected to the highest of the frequencies for which it is rated and to the maximum rated current, and a complete heat run is made under these conditions.

Electrical condensers are often called electrostatic condensers. This name hardly applies to the mica condensers used in high-frequency circuits. The main use of mica condensers is to store electical energy in the oscillating circuit and to deliver it back with a minimum loss of energy. It is also often used to transfer the energy from the generating circuit to the antenna or a transmission line.

A concrete example will simplify the discussion: given a self-excited master oscillator of the Hartley type, with a one-kilowatt vacuum tube capable of withstanding 15,000 volts d-c potential on its plate; determine the complete rating of the mica condenser for the main tank circuit. The frequency desired is 100 kilocycles.

The solution of the example is as follows: since it is a master oscillator that is desired, a circuit of high stability is required first. Nearly all the power output of the tube can be consumed in the losses of the oscillating circuit for the purpose of obtaining as high a ratio of circulating energy to power output of the tube as possible. An oscillating and coupling circuit of one per cent effective power factor is not out of order. This means that the total circulating energy in the oscillating circuit will be 100 kilovolt-amperes, since the tube is capable of delivering one kilowatt of radio-frequency power.

With 15,000 volts direct current on the plate and swinging this plate clear to zero potential on the negative peak of the radio-frequency voltage, the radio-frequency voltage on the plate is 10,600 volts effective. In a Hartley oscillator, the radio-frequency voltage on the tank

condenser is slightly higher than the radio-frequency voltage on the plate of the tube, the ratio of the voltages being around 1.2 to 1. This gives the radio-frequency voltage on the oscillating circuit as 12,600 volts, effective. Dividing 100 kilovolt-amperes by 12.6 kilovolts, the value of tank current of 7.9 amperes is obtained. The next step is to calculate the impedance and the capacity of the condenser. Dividing 12,600 by 7.9, the impedance value of 1590 ohms is obtained. The corresponding value of capacity is 0.001 microfarad.

The rating of the tank condenser, or rather the bank of condensers for the tank circuit appears from the above calculations to be as follows:

The condenser bank is to have a total capacity of 0.001 microfarad and must be capable of withstanding an operating current of 7.9 amperes at 100 kilocycles without overheating.

This rating, as worded above, is complete as there is no other voltage outside of the one imposed on the condenser by the oscillating circuit. Having given the current carrying capacity and the operating frequency of the condenser, the operating voltage is their function and so is the kilovolt-ampere rating of the bank. In other words, specifying capacity, operating current, and operating frequency automatically specify operating radio-frequency voltage and energy-storing ability in kilovolt-amperes.

The importance of the energy-storing ability of a condenser becomes clearer when the power factor of the condenser is considered. While the power factor of the complete oscillating circuit may be as high as 1 per cent, the power factor of a mica condenser, short waves excluded, is never more than one-tenth of one per cent and more frequently nearer one-half of that value. Taking the latter value and applying it to the example, energy dissipation of 100,000 times 0.0005 equal to 50 watts is obtained. The condenser bank must, therefore, be capable of dissipating at least 50 watts without overheating. By way of comparison, the power transformer in a receiving set gets quite hot dissipating only about ten watts.

There are other oscillating circuits beside Hartley's and in some of them the direct-current potential impressed on the plate is also impressed on the tank condenser. In such a case, the radio-frequency voltage is superimposed on a d-c voltage and the resultant peak voltage will be much higher than in the case above.

A description of the performance of a single section under various conditions will be in order at this time. The following discussion is only another example of performance of a particular type of section, with particular margins, particular impregnation, particular size and kind

of mica, etc. It should not be generalized in any way as to the values given. The procedure described, however, is quite general.

A particular section of mica condenser after it has been vacuum-impregnated in paraffin, is subjected to a 60-cycle potential in a dark room. It is placed in a paraffin bath which is kept at a temperature slightly above the melting point of paraffin. This permits an easy observation of the corona effect. The voltage is gradually brought up at a rate of about 100 volts per second. Let us assume that when 4000 volts, effective, is reached, a small speck of blue appears suddenly on the edge of foil. It is of the size of a needle tip. When the lights are turned on, this speck is already wider and a bubble of gas has formed around it. The voltage had been kept at the value at which this corona appeared but the bubble and the brush are growing very rapidly. Before long, all foils are surrounded by corona, and gas bubbles reach the surface of the liquid paraffin.

The voltage is gradually brought down at the same rate as before. The corona decreases in size but does not disappear until a voltage as low as 1200 volts is reached. The voltage then is brought to zero. The condenser is cooled and left in the paraffin for a while. A few fours later the bath is warmed up again with the main object of giving transparency and of bringing the temperature of the impregnating medium to the normal operating value.

When the section can be seen again, it is at once noticeable that the gas bubble which was built by the corona on the original test, is still there. When the voltage is again gradually applied, the corona appears at the value at which it last disappeared; i.e., 1200 volts. The conclusion follows that the section has been damaged more or less permanently.

If we leave the voltage on for a long time, the temperature may rise to a point at which solder and foil will melt and the section will be damaged completely. If the gas bubble is removed by vacuum-treating the section again, the corona will not appear again until a potential of 4000 volts is reached. If the potential is brought up at a slightly faster rate and corona formation is disregarded, the same section will be punctured at around 5000 volts, effective. This breakdown voltage will not vary much with the duration of corona and with the previous history of the condenser, provided the temperature rise on the surface of the mica due to the corona is not excessive. It will depend more on the kind of mica used and on its thickness, of course.

If a radio-frequency voltage is applied to the same kind of section under a similar set of conditions, the corona will form at a much lower voltage. This voltage will be as low as 800 volts at 100 kilocycles and probably only 600 volts at 1000 kilocycles. The behavior of the gas

bubble with reduced voltages applies here again, as previously described.

It takes energy and, therefore, time to make the gas bubble and for that reason a high-frequency voltage of a very high value but of a very short duration may be applied to the section without forming a gas bubble and, therefore, without damage to the section.

If the frequency of the applied voltage is increased and the short-wave range is reached, a very high temperature rise in the section at a relatively low radio-frequency voltage is noticed. This is due to the rapidly increasing power factor of the condenser at those frequencies. It is due to straight resistance effect of the foil, to eddy current losses in the conductor, and possibly to the increase in dielectric absorption.

The foregoing allows a discussion of the performance of a complete condenser; i.e., of a stack of several sections connected in series, enclosed by a case which is filled with compound of relatively high melting point.

In order to pass the first "section high pot" test, the mica in the sections must have the breakdown point reasonably higher than this test voltage. The finished condenser, when tested after the last vacuum treating, must have enough sections in series so that when the last high voltage test is applied no corona and consequently no air bubbles can form. The area of the case must be such as to dissipate all the watts that are dissipated when storing energy at high frequency. The heat dissipated in each pair of mica sheets and foil should not be more than the paraffin can carry away to the casing. If the last condition is not satisfied the heat will gradually accumulate and finally evaporate a quantity of paraffin. The result will be the same as with the bubble.

For those not acquainted with the reasons why corona forms more easily in air or gas than it does in paraffin, the following elementary explanation should be sufficient: Corona is simply a partial breakdown of the dielectric. When dielectrics are in series, one of them may break down while the other will still hold. The dielectric strength of paraffin is several times that of the air. The strength of mica, in the thicknesses used, is greater than that of paraffin. Therefore, when there is only paraffin filling all the space between the foil and mica it will break at much higher voltage than a pocket of air. The contact between mica and foil can hardly be made perfect and even if it were possible, the edge effect would still remain.

Consider a mica condenser consisting of ten series sections, each section having a capacity of 0.01 microfarad, giving a total capacity of the condenser at 0.001 microfarad: the case of the condenser under consideration is capable of dissipating ten watts with a total temperature

rise of 20 degrees C. The power factor of the condenser is 0.05 per cent for all radio frequencies up to and including 1000 kilocycles, 0.12 per cent at 3000 kc and as high as 0.5 per cent at 10,000 kc or 30 meters. Taking the values for the individual sections from the experiment described above, the following data can be added: Section breakdown voltage is 5000 volts per section; corona point 4000 volts per impregnated section at low frequencies, 800 volts at 100 kilocycles and around 600 volts per section for higher frequencies.

In order to find the maximum allowable rating of such condenser, the following line of reasoning can be followed:

If the section breaks down at 5000 volts, effective, it should not be tested for imperfections at a voltage higher than three-fifths of the breakdown voltage and operated at one-fifth of the same value. This would mean that section test voltage should be 3000 volts, effective, and the operating effective voltage should not exceed 1000 volts per section. The corona point of 4000 volts per section is quite remote, provided the air is all taken away by the vacuum-impregnating. Fixing the operating voltage at 1000 volts per section gives a total effective operating voltage for the condenser at 10,000 volts. This rating applies to low frequencies only. It would appear that for direct current this rating could be interpreted so that a d-c potential corresponding to peak of the rated alternating current could be permanently applied to the condenser. This, however, is not true, as experience shows that the d-c rating should not exceed the effective low-frequency rating of the condenser. The impedance of the condenser under consideration at 1000 cycles is 159,000 ohms so that the current through it at that frequency is only 63 milliamperes for 10,000 volts, effective, and the energy stored only 630 volt-amperes. For power factor of 0.05 per cent, this gives heat dissipated in the condenser as 0.315 watt, a value too small to produce a readable temperature rise. The condenser is essentially a potential device at these low frequencies. At 100 kilocycles the picture changes somewhat. The impedance of the condenser is still very high, 1590 ohms in fact, but the voltage allowable per section must be reduced to not more than 300, due to the corona point's being much lower at those frequencies. This limits the total operating voltage on the condenser to 3000 volts at a frequency of 100 kilocycles; dividing 3000 volts by the impedance, the value of permissible current equal to 1.9 amperes is obtained; the corresponding circulating energy is 5.7 kilovolt-amperes.

At 300 kilocycles the condenser impedance is down to 530 ohms; if the total radio-frequency voltage across it should not exceed 3000 volts, the radio-frequency current of 5.65 amperes is permissible and the cir-

culating energy amounts to 17 kilovolt-amperes. The power factor at that frequency being 0.05 per cent, the heat to be dissipated by the case becomes 8.5 watts. The condenser at this frequency works as both a potential device and also as an energy-storing device.

At 1000 kilocycles the condenser becomes an energy-storing device altogether. Its 10 safe watts of heat dissipation limit the rating. With power factor of 0.05 per cent it allows storing of 20 kilovolt-amperes of circulating energy. Its impedance is only 159 ohms and the voltage corresponding to this amount of circulating energy is 1780 volts total or 178 volts per section, which is altogether safe from the corona standpoint. The current rating is obtained in the same manner being equal to 11.2 amperes.

At 3000 kilocycles, the product of the circulating energy and the power factor is the only limiting factor. The calculation is the same as for 1000 kilocycles; the value of power factor is the only thing that is changed—from 0.05 to 0.12 per cent. The ratings obtained are as follows: Circulating energy 8.9 kilovolt-amperes, current 11.4 amperes with voltage of 605 volts total or only 60.5 volts per section. For 10,000 kilocycles the calculation is identical with the latter two and gives 2 kilovolt-amperes of circulating energy, current of 11.2 amperes and voltage 178 volts total or only 17.8 volts per section.

A little reasoning will justify the practicability and safety of the statement that when a d-c and radio-frequency voltage are superimposed, the sum of the d-c voltage and the effective a-c should not exceed the effective voltage rating of a condenser.

On the basis of the foregoing discussion, a complete rating for the condenser under consideration can be formulated as follows:

> Electrical condenser of 0.001 microfarad capacity; maximum effective operating voltage 10,000 volts; maximum d-c operating voltage 10,000 volts; radio-frequency carrying capacity 1.9 amperes at 100 kilocycles, 5.65 amperes at 300 kilocycles, 11.2 amperes at 1000 kilocycles, 11.4 amperes at 3000 kilocycles, and 11.2 amperes at 10,000 kilocycles. For superimposed direct and alternating current, the sum of effective a-c with the d-c voltage should not exceed 10,000 volts.

Table I gives some of the above information in a convenient form. In modulated circuits, the most severe condition is when the carrier is modulated 100 per cent by a frequency constant in its value and amplitude. Using "I" to denote the effective value of current through the bank when no modulation is present, the peak values of the current without modulation is 1.414 times I: the peak value of the current

with 100 per cent modulation is 2.83 times I; and the effective value of the modulated current is 1.223 times I.

If the transmitter is used for speech transmission the peaks will occur at rather long intervals. The occurrence of peaks, therefore, is altogether transient and the effective value of current is the only important factor in the choosing of a mica condenser for the job. For the lower end of the band of broadcast frequencies and also for still lower frequencies modulated 100 per cent by continuous audio frequencies, a safety factor of about 1.2 should be applied to the rating derived by

TABLE I

CURRENT—VOLTAGE—ENERGY RATING OF THE 0.001-MICROFARAD MICA CONDENSER DESCRIBED IN THIS PAPER

Frequency, Kilocycles	Wavelength, Meters	Impedance, Ohms	Rated Current, Amperes	Rated Voltage, Effective	Rated Energy, KVA
Direct Current	—	infinite	—	10,000	—
1		159,000	0.063	10,000	0.63
100	3,000	1,590	1.9	3,000	5.7
300	1,000	530	5.65	3,000	17.0
1,000	300	159	11.2	1,780	20.0
3,000	100	53	11.4	605	8.9
10,000	30	15.9	11.2	178	2.0

the above methods. True, the peaks of radio frequency occur at an audio-frequency rate and the duration of them is almost transient; almost, but not quite. At each peak of the audio frequency, and especially a low audio frequency, there occur many radio-frequency cycles of nearly the same amplitude in direct succession.

In the first example given in this paper, a set of requirements for a particular tank condenser bank was calculated. It was to have a capacity of 0.001 microfarad and carry a current of 7.9 amperes safely at 100 kilocycles with no modulation. If additional requirements of 100 per cent modulation and of capability to block 15,000 volts direct current superimposed, this example becomes a typical problem in transmitter design.

On account of the tube limitations the power for the modulated current seldom can be increased; therefore the effective value of the modulated current will remain 7.9 amperes. The unmodulated effective value, of course, will go down in 1.223-to-1 ratio.

If the transmitter is to be used for other than speech transmission, a safety factor of at least 1.2 should be applied. This gives the value of effective rated current at 9.5 amperes at 100 kilocycles. At 100 kilocycles the impedance of a 0.001 condenser is 1590 ohms, which at 9.5 amperes gives 15,000 volts, effective. Together with 15,000 volts direct current this calls for a bank capable of withstanding 30,000 volts, effective. The circulating energy rating is 143 kilovolt-amperes and as at this frequency the power factor of a mica condenser is around

0.05 per cent, the heat dissipated is 72 watts approximately. The bank under consideration can be built of a great number of series-parallel combinations. To illustrate the choosing of condensers to do a particular job, several of such satisfactory combinations are listed below:

There is no standard single unit to satisfy the requirements. Four units in parallel, each rated at 0.000250 microfarad, 30,000 volts, effective, and each capable of carrying 2.5 amperes at 100 kilocycles will be one answer.

Four units in parallel-series combination, each rated at 0.001 microfarad, 15,000 volts effective, and capable of carrying 5 amperes at 100 kilocycles is another solution.

Two series and each rated at 0.002 microfarad, 10 amperes, and 15,000 volts, effective, is still another solution.

Of the three, the number 3 will probably be the most economical.

As was already mentioned, the values of this paper are purely illustrative and under no condition should be generalized. This paper is tutorial in nature and is not a record of any specific development. It is a record of standard engineering practice with a few theoretical considerations and is intended to help the designer as well as the user of mica condensers in his choice of proper material for a job on hand.

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AN EXAMINATION OF SELECTIVITY*

By

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Summary—*A review of the literature on selectivity including the important recent contributions shows the necessity for coördination of the results and clarification of the definitions. The present selectivity requirements are developed and a simple mathematical treatment is expanded to meet them. The criterion for uniform ability to reject undesired signals, for both condenser and inductance tuning, results from this calculation. The relation of the selectivity curve, as now taken and presented, to the actual performance of the receiver is discussed, and the central portion is compared mathematically with the fidelity characteristic. Possible improvements in the definition, method of measurement, and presentation of data, are suggested.*

Selectivity is a persistent and increasing problem. We have at our command to-day the means for securing any desired degree of sensitivity within reason, and the quality of the audio amplifier is limited only by what we are willing to spend for it. But that characteristic of the receiver by which it rejects undesired signals is not yet in a condition which may be regarded as satisfactory. The problem, while present in all classes of radio receivers, is particularly difficult in broadcast receivers, because they must be tuned over a very considerable band of frequencies.

The present paper is the result of a study of the literature on this subject, which is remarkably meager. For example, out of over 800 papers published by the Institute of Radio Engineers since its organization in 1912, less than a dozen make any direct contribution to the subject, and only two are addressed directly to it.

We have been in the habit of thinking of the signals as being of any frequency within the band. This was the result of several causes. Continuous tuning has been used from the first in broadcast receivers. The conditions during the early days of the art were chaotic, and this contributed to the very slow adoption of straight-line frequency tuning. By far the greater part of the laboratory work has been carried out with devices on which the signals appeared to have a much greater separation at one end of the dial than at the other end.

Another factor which has played an important part is that, until very recently at least, it has been impossible to produce circuits that

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had anything like the same response at the two ends of the range. Tuned circuits of the commonly used types, although they can now be so compensated as to give reasonably constant gain, still exhibit a much greater ability to reject undesired signals at the lower frequencies than at the high. Thus the orderly arrangement of the signals themselves has been masked by the imperfections of the apparatus we have used to reveal them, and this has been reflected, to some extent at least, in our analytical work.

It is important, therefore, to emphasize the following simple facts, and to ask that they be kept definitely in mind in connection with what follows. The entire radio-frequency spectrum is divided into bands assigned to various services. In each band there is a definite number of channels. Each channel has a definite width in kilocycles, and, in general, all the channels in any one band have the same width. Each channel is designated by its central frequency, and transmitting stations are required to maintain their carriers within very close limits of this central frequency.

In the broadcast band there are ninety-six discrete channels. The designating frequencies are spaced 10 kc apart, and the limits of each channel are 5 kc above and below these "carrier" frequencies. And these carrier frequencies, expressed in kilocycles, end in zero.

The discussion and conclusions of this paper, although addressed particularly to the broadcast band, apply equally well to any other band or service.

Because we are concerned only with selectivity, we shall assume that the audio amplifier has a strictly uniform response over the entire audio range permitted by the channel width, that is, from zero to 5000 cycles. It will also be convenient to think of the tuning mechanism as being of the straight-line frequency type.

The three principal characteristics of a broadcast receiver are sensitivity, fidelity, and selectivity. Unfortunately they are not entirely independent of one another, as we usually think of them. To most of us, at least, they have been continuous functions of frequency, and one has merged into the other. If we take our concept of ninety-six discrete channels into account, however, the three characteristics become immediately distinct. Sensitivity and fidelity apply to the desired channel. Selectivity applies to all the other channels. It is not concerned with anything closer to the desired signal than 10 kc, or at the least, 5 kc.

Sensitivity and fidelity are defined, as they should be, without reference to each other, or to the third characteristic. This is not true, however, with respect to selectivity. It seems to have been the bridge

by which the other two were connected. This, I believe, is neither necessary or desirable. Let us look at some of the definitions, which I shall quote.

"The selectivity of a receiver is the degree to which it is capable of differentiating between the desired signal and signals of other carrier frequencies."[1] This definition contains the idea of carrier frequencies, although it does not use the word channel. It defines the property, however, in terms of its relation to another property.

"Selectivity is the ability of a radio receiving set to select any particular wavelength and exclude others," "the ability of the receiver to differentiate between signals of different frequencies," "that property of a receiver which enables the user to separate desired programs from undesired ones."[2]

"Selectivity means the absolute choice of wanted transmissions without interference of any kind. It is the comparative response of a desired station and one that is undesired, and that is determined by the response ratios and not by curve shape."[3]

"Selectivity is the width of the band at some percentage of maximum gain." "The ratio of the resonant to the nonresonant voltage across the condenser in the tuned circuit, for constant input."[4]

In another case we are given an equation for the output voltage ratio, and this expression is reduced so as to give the band width at half amplitude.[5]

These definitions show a lack of agreement not on the general nature of the property, but on the best method of expressing it. They also show a dissatisfaction with previous definitions, and perhaps with the word itself. They illustrate the dependence, not only of the definitions themselves, but also of the suggested method of measurement, upon other properties of the receiver. None of them suggest the important fact that the signals to be discriminated against, are equally spaced in frequency.

In an ideal receiver, the admitted band would be 10 kc wide, flat across the top, and vertical on the sides. The response to channels to which the receiver was not tuned would be zero, or at least sufficiently small to be inaudible in the translating device. There would be no necessary relation between the total amplification represented by the

[1] Standardization Report, 1931, page 121, Institute of Radio Engineers.
[2] "Radio Handbook" 1931, page 40, Moyer and Wostrel.
[3] K. W. Jarvis, "Selectivity of tuned radio receiving sets," Proc. I.R.E., **15**, 401; May, 1927.
[4] B. de F. Bayly, "Selectivity, a simplified mathematical treatment," Proc. I.R.E., **19**, 873; May, 1931.
[5] W. A. MacDonald and H. A. Wheeler, "Theory and operation of tuned radio-frequency coupling systems," Proc. I.R.E., **19**, 738; May, 1931.

band, and the deamplification or attenuation represented by ce of the characteristic.

amplification in the admitted band would be dependent upon ho. eak a signal it was desired to receive. The deamplification in the excluded bands would be dependent upon how strong a signal it was desired to exclude. There is no problem in receiving the strongest signal, or in excluding the weakest. The deamplification or attenuation of the undesired signal would not depend upon the amplification and final output of the desired signal, since during periods of no modulation on the desired signal, the undesired should still not be heard.

The existing definitions and methods of measurement seem, therefore, to be written around what is conceived to be possible in the physical apparatus with which we have to deal, rather than around what is obviously desirable. They bring the selectivity characteristic right up to the frequency of resonance, in spite of the fact that it is desired to receive, not to reject, all frequencies within 5 kc of the frequency to which the receiver is tuned. They are definitely associated with the resonance curve, and in most of the mathematical treatments, assumptions are made which limit the accuracy of the results, except in regions very close to resonance.

As a tentative proposal, made with due regard to the fact that it should have adequate discussion, it is suggested that selectivity should be defined, generally, as that property of a receiver by which it is able to reject signals to which it is not tuned, and that, in measurement, this property be stated in terms of field strength, for each channel above and below resonance, which will give an output, specified in milliwatts, which we can agree is inaudible. Such a definition is independent of the sensitivity of the receiver, and since it is stated only for channels above and below resonance, it has no relation to the fidelity characteristic. It is an over-all property of the entire receiver. The property thus defined is not measured in the present method, nor shown by the resulting curves.

Neglecting that portion of the curve which lies within 5 kc of resonance, the selectivity curve shows, in the form of a ratio, the strength of signal necessary to produce full output, that is, the standard output at which all measurements are made. It is obvious that a very much weaker signal would be sufficient to produce an audible response amounting to actual interference. If the receiver were being operated at 50 milliwatts output, then an output power of 0.5 milliwatt for an undesired signal might be very objectionable.

In the actual operation of the receiver, for any condition under which it can be successfully used, the attenuation of the radio amplifier

operates to reduce both the carrier and the side band amplitudes of any undesired signal to values well below those for the desired signal. The ability of the receiver to reject these signals, however, depends also upon the type of detector used, since this tube tends to increase any ratio that may exist on its grid. The difference between linear and square-law detectors, in this respect, for signals or side bands quite close to the desired signal, has been discussed from a theoretical standpoint in a recent paper by Aiken.[6] The effect of the desired carrier, modulated or unmodulated, is also given. This is the well-known masking effect.

In the selectivity curve as now taken, the carrier and side band amplitudes at the detector grid are held constant. No resonant carrier is used when the off-resonance measurements are made. Thus the several effects in the detector tube which alter the over-all ability of the receiver to reject undesired signals, are not shown by the curve. The detector in most modern receivers is so connected as to give linear rather than square-law results, but it is recognized[7] that it is not strictly linear, and that it approaches linearity only for the higher signal voltages on its grid. Contrary to what might at first be expected, it assists to a greater degree than the square-law detector in the rejection of undesired signals which have been previously attenuated so that the ratio at the detector grid is favorable. Now more than ever before, therefore, it is important to include the effect of the detector in selectivity measurements.

The central portion of the selectivity curve represents, in a general way, the effect of the radio attenuation on the audio output characteristic. It can be shown that this is not an accurate representation of the effect, and that the greater the radio attenuation, the greater will be the disagreement. The complete computation is given in an appendix. The general method is as follows.

The same input signal is used for the resonant reading on the selectivity curve, and for the reference reading on the fidelity curve. This result is taken as unity, or 100 per cent, in both cases, but is plotted at zero frequency in one case, and at 400 cycles in the other. It is usual, and logical, to plot the audio frequency on a logarithmic scale, and this places the 400-cycle reading almost exactly at the center of the audio range. If the selectivity curve is plotted in the same way, the unity value for the reference reading cannot be plotted at zero frequency,

[6] C. B. Aiken, "The detection of two modulated waves which differ slightly in carrier frequency," Proc. I.R.E., 19, 126; January, 1931.

[7] Stuart Ballantine, "Detection at high signal voltages," Proc. I.R.E., 17, 1158; July, 1929.

where it belongs, since this does not appear on the sheet. If the reading for the lowest frequency measured is taken as unity, it should logically be plotted at the left-hand edge of the sheet. If there is any attenuation whatever for a signal 400 cycles off resonance and modulated at 400 cycles, it can be shown that taking the 400 cycle selectivity reading as unity to make the two curves agree at this point, introduces a disagreement at all other points. The fact that there is an attenuation of the 400-cycle side bands in the fidelity reading does not bring the curves into agreement, since this is ignored by taking this value as unity.

In general, this attenuation is very slight, but if it is to be neglected, then we are assuming, not that there is no reduction of the 400-cycle side bands, but that there is no attenuation of a signal 400 cycles detuned. This might be allowable in simple tuned radio-frequency receivers, but is certainly questionable in good superheterodynes, and is considerably in error in the case of experimental receivers employing piezo-electric crystals.

The consideration of the question of the reference readings brings us to the more important question of whether the effect of the radio amplifier will be the same for two different types of signal; namely

1. A resonant signal modulated at any audio frequency $p/2\pi$.
2. A nonresonant signal, $p/2\pi$ cycles off resonance, and modulated at 400 cycles.

To determine this, we note first that the detector acts to produce all possible beats between the radio frequencies impressed upon its grid, and that one of these beats is the audio voltage which we measure in the output circuit. We then assume attenuations for each of the single frequencies which will reach the grid in the two cases, that is for each carrier and each side band frequency. The coefficients at the detector grid can then be written, and the results of the rectification, for the principal audio term in the output circuit, for both linear and square-law detectors, can be computed.[6]

The result of this analysis is the following conclusion: (1) that if there is any attenuation whatever between zero and 5000 cycles, the two curves will not agree, and that the greater the attenuation, the greater will be the disagreement; (2) that the central portion of the selectivity curve does not accurately depict the effect of the radio amplifier on the side bands of the desired station. This means that for highly selective circuits, the selectivity curve has no useful meaning in this range, and this portion of the curve should therefore be discarded, or at least not shown on curves intended for publication.

The extent of the disagreement for a rather extreme case is shown in Fig. 1. The curve *FFF* is fidelity measured in the standard way.

The curve CCC is the product of the selectivity curve and the audio amplifier characteristic. At 3000 cycles, for example, the fidelity is actually 60 per cent, but the product curve shows only 4.3 per cent. Similarly great discrepancies exist below 100 cycles.

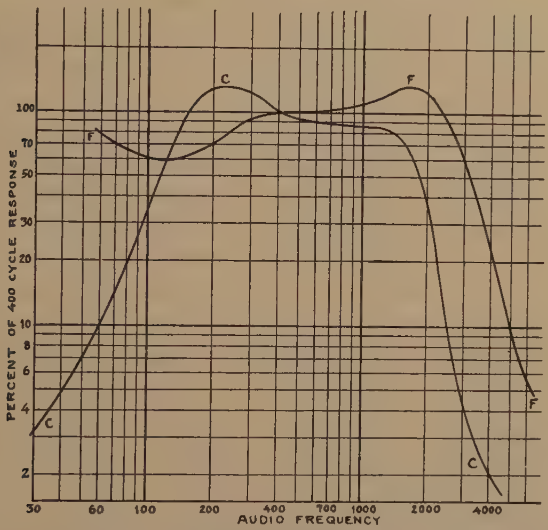

Fig. 1.—An exaggerated case of disagreement between measured and calculated fidelity.

Mathematical Investigation

In general, the mathematical treatments of selectivity have consisted in the following steps:

1. Development of an equation for the voltage delivered by a tuned circuit, in terms of the input voltage and the impedance.
2. Determining the value of this equation at resonance.
3. Dividing the second equation by the first to give the ratio of the output voltage due to a resonant input, to the output voltage for a nonresonant input.

Such expressions are perfectly general, but unfortunately quite complicated, particularly in the case of coupled circuits. In order to secure a simplification, a single symbol is substituted for some portion, and such symbols soon take on the importance of a definite and measurable property of the apparatus or some part of it. In most cases, the portions thus denoted by a single symbol are functions of frequency and in addition contain quantities which although nominally constant, actually are also functions of frequency.

To a certain extent, this difficulty can be avoided by putting those

terms which involve the frequency in the form of a percentage difference. Such treatments are of only limited value, however, since the signals are separated by a constant absolute frequency difference rather than a constant percentage frequency difference.

Most of the mathematical discussions of selectivity are not suited for other reasons to our present purpose. In one,[3] for example, it is assumed that there is no series resistance. Since it is the allowable variations in this series resistance which we wish to determine, this analysis will not serve. In another and fairly complete article,[8] in which the performance of various types of coupled circuits are examined, the assumption is made, for the purpose of simplifying the mathematical treatment, that the resistance varies directly with the frequency. Certainly, if any improvements in the uniformity of radio-frequency selectivity are to be made, they will only come through a controlled manipulation of the dissipative resistances by which they are proportional to some function of the frequency other than linear.

In the calculation which follows, the general equation for the selectivity of a parallel tuned circuit at any off-resonance frequency is stated for two different values of the resonant frequency, and these two values are equated to determine the conditions which must be fulfilled if the selectivity is to be the same at these two resonant frequencies, or, in other words, constant over a considerable band. The two resonant frequencies may be the two ends of the broadcast band.

Having thus arrived at an equation for constant selectivity, a computation of the numerical values of the coefficients is made to determine the exact nature of the result so far as broadcast receivers are concerned. From this we are lead to further simplifications and some general conclusions which appear to be of considerable interest, and which point out certain definite limitations and advantages.

The following expression for the selectivity of a single circuit is given by Bayly[4]

$$\frac{E_r}{E} = \sqrt{K^2 + Q^2(K^2 - 1)^2} \quad \text{where } K = \frac{\omega}{\omega_r} \text{ and } Q = \frac{\omega_r L}{R} \cdot \tag{1}$$

Using small letters to denote all quantities at the low-frequency end of the broadcast range, and large letters for the high-frequency end, we state one condition for constant selectivity by writing

$$k^2 + q^2(k^2 - 1)^2 = K^2 + Q^2(K^2 - 1)^2 \tag{2}$$

[8] E. S. Purington, "Single- and coupled-circuit systems," Proc. I.R.E., 18, 983. *See also* K. S. Johnson, "Transmission Circuits for Telephonic Communication," page 79.

which yields, upon simplification

$$q = \sqrt{aQ^2 + b} \quad \text{where } a = \frac{(K^2 - 1)^2}{(k^2 - 1)^2} \quad \text{and } b = \frac{K^2 - k^2}{(k^2 - 1)^2}. \tag{3}$$

Remembering that we are dealing with ninety-six discrete channels, and that our interest for the moment is in separating these channels, it is interesting to make numerical substitutions for K and k, and to determine a and b, and thus the indicated ratio between Q and q for constant selectivity. Values have therefore been calculated in Table I for each of the first five channels above resonance, using 550 as the channel of resonance at the low-frequency end, and each of the last five channels successively at the high-frequency end. This gives the extreme conditions for variation in the quantities involved.

TABLE I

Frequency ω_r	ω	k	k^2	$(k^2-1)^2$	
550	560	1.018181	1.03661087	0.001340323	
	570	1.036363	1.07398357	0.005473303	
	580	1.054545	1.11201811	0.012547148	
	590	1.072727	1.15071449	0.022714180	
	600	1.090909	1.19007271	0.036127119	
		K	K^2	$(K^2-1)^2$	F_0/f_0
1490	1500	1.006711	1.01345635	0.000181068	2.709090
1480		1.013513	1.02719592	0.000739593	2.690909
1470		1.020408	1.04122432	0.001699266	2.672727
1460		1.027397	1.05544486	0.003073862	2.654545
1450		1.0344827	1.07006814	0.00490531	2.636363
		K^2-k^2	$a=\dfrac{(K^2-1)^2}{(k^2-1)^2}$	$b=\dfrac{K^2-k^2}{(k^2-1)^2}$	K/k
560	1490	−0.0231545	0.13505596	17.9532700	0.9887345
570	1480	−0.04678765	0.13512743	8.5483387	0.9779514
580	1470	−0.07079379	0.13544360	5.6422215	0.9676280
590	1460	−0.09516686	0.13563705	4.1897554	0.9577428
600	1450	−0.12000457	0.13589613	3.5173700	0.9482757

It will be noted that the value of a is quite constant for these five channels, deviating from the value 0.135 by less than 1 per cent. Obviously this variation would be less for two groups of channels taken at any other points in the range. The value of b, however, shows considerable variation, running from 17.9 for the adjacent channels to 3.51 for the channels 50 kc removed.

In Table II the calculation has been continued assuming arbitrary values for Q at the high-frequency end, and the value of Q/q determined. It will be noted that the factor b has its greatest effect for the smallest value of Q, which corresponds to the poorest coil. But even with the worst coil, its effect is relatively unimportant except on the

adjacent channel. This means, in general, that we can expect some difference in adjacent channel selectivity even when we have so designed our circuits as to get constant selectivity on the second and subsequent channels, unless unusually good coils are used.

TABLE II
CALCULATION TO DETERMINE THE RATIO Q/q

Channel	Q	Q^2	aQ^2	b	aQ^2-b	q	Q/q
I	20	400	54	17.9	36	6.00	3.33333
	40	1600	216		198	14.07	2.84292
	60	3600	486		468	21.63	2.77392
	80	6400	864		846	29.08	2.75103
	100	10000	1352		1334	36.52	2.73822
II	20	400	54	8.54	46	6.78	2.9498
	40	1600	216		208	14.42	2.7739
	60	3600	486		478	21.86	2.7447
	80	6400	864		856	29.25	2.7350
	100	10000	1352		1344	36.66	2.7332
III	20	400	54	5.64	49	7.00	2.8571
	40	1600	216		211	14.52	2.7548
	60	3600	486		481	21.93	2.7359
	80	6400	864		859	29.30	2.7303
	100	10000	1352		1347	36.70	2.7247
IV	20	400	54	4.18	50	7.07	2.8288
	40	1600	216		212	14.56	2.7472
	60	3600	486		482	21.95	2.7334
	80	6400	864		860	29.32	2.7285
	100	10000	1352		1348	36.72	2.7233
V	20	400	54	3.51	51	7.14	2.8011
	40	1600	216		213	14.59	2.7415
	60	3600	486		483	21.97	2.7309
	80	6400	864		861	29.34	2.7266
	100	10000	1352		1349	36.74	2.7218

Noting that the value of Q/q, except for poor coils, is very close to the frequency ratio, we may write

$$\frac{Q}{q} = \frac{\Omega Lr}{\omega lR} \quad \text{but} \quad \frac{Q}{q} = 2.73 \quad \text{therefore} \quad \frac{\Omega L}{R} = 2.73\frac{\omega l}{r} \cdot \tag{4}$$

If L is held constant, as it is in condenser tuning, then the total effective resistance must remain constant. This can only be accomplished so far as we know, by artificially increasing the resistance at the low-frequency end to compensate for the natural decrease. If L is variable, and is used to tune the circuit, then

$$\frac{L}{R} = \frac{l}{r} \quad \text{but} \quad \frac{l}{L} = 7.43 \quad \text{therefore} \quad \frac{r}{R} = 7.43. \tag{5}$$

This means that the resistance may be roughly $7\frac{1}{2}$ times as great at the low-frequency end as it is at the high, and still maintain constant band width, a remarkable advantage for inductance tuning.

Referring again to Table I, it is seen that the value of a, at least for the first five channels either side of resonance would be very closely

the same for any smaller frequency range within the broadcast band. The value of b would be smaller for such a restricted range, and since this is the factor which causes Q/q to vary near the resonance, we can say that our solution, equation (5), applies throughout the entire frequency band, at least to a very close approximation.

L and R, of course, are the inductance and resistance in a single circuit. In a simple coupled system with a transformer whose untuned primary is connected to the plate of a vacuum tube, and whose tuned secondary is connected to the grid of the succeeding tube, these two quantities become complex.

Several different methods of stating mathematically the effect of the primary and the tube on the secondary have been given,[5,7,8] but there would be no advantage in repeating them here. In general, the inductance is decreased and the resistance is increased by an amount which is itself a function of the frequency. But the important conclusion is that for either type of tuning, and from the point of view of channel separation, it is L/R and not $\omega L/R$ which must be taken as the measure of selectivity. This is the quantity which determines the ability of the receiver to reject undesired signals at any point in the range. The quantity Q is a matter of mathematical convenience in simplifying the original equations for curve shape.

Equation (1), which we have chosen for this computation, is not limited by any assumptions, having been developed directly from the usual general equation for an a-c circuit, which states the current in terms of the voltage and the impedance. We have been using the word "selectivity" in its generally understood sense, but the equation we have operated on gives the ratio of the voltages across the parallel tuned circuit, assuming a constant input voltage. This is the equation of a resonance curve, and not the equation of the selectivity curve as taken by the standard method, in which the output voltage, and therefor the voltage on the detector grid, is held constant.

So far as the tuned circuits are concerned, and assuming that there is no overloading of the tubes by which the amplification becomes a function of the input voltage, it is allowable to invert the equation, and read it as the ratio of the input rather than the output voltages. However, there may well be overloading of the tubes, particularly the first tube, as the input is increased to keep the output constant. This danger is made the greater by holding the output power at the value chosen for the sensitivity curve, a power level appropriate for a desired signal, but certainly not for an undesired signal. It is also obvious that as the selectivity of the receiver is increased, the input voltage must be made

higher, still further increasing the probability of nonlinear amplification. This is indicated diagramatically in Fig. 2.

In the standard measurement, the curve is usually limited to a range quite close to resonance. This results from the simple fact that there is a limit to the voltage that can be delivered by the signal generator. If the output power were held constant at a level representing acceptable rejection of undesired signals, the curve could be considerably extended above and below resonance.

Attention has been focused, both in measurement and in mathematical investigation, upon the central portion of the curve. In the mathematical treatments it has been assumed that ω/ω_r would not be

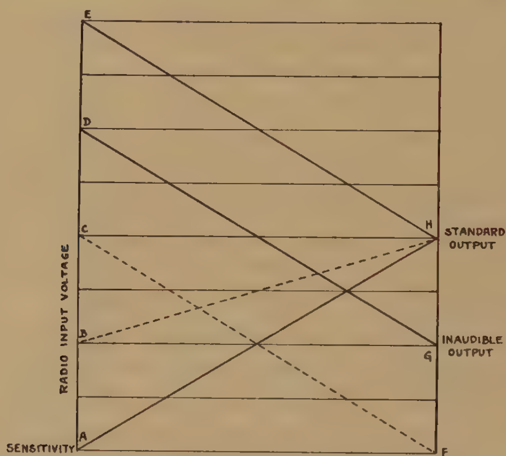

Fig. 2—Diagram illustrating the general relations between input and output voltages.

more than one or two per cent. At 550 kc this excludes all but the adjacent channel. The standard curve sheet on which the measurements are usually plotted shows only three channels on either side. The central portion of the curve, occupying one-third of the sheet, has no relation to the ability of the receiver to reject undesired signals. And the portions of the curve lying between the ordinates representing the ratios for each channel above and below resonance are also without significance, since in the scheme of broadcasting there will never be any signal inputs at these frequencies.

The band width of such a curve has a technical, but not a practical interpretation. What we desire to know is not what frequencies would fall at a specified input ratio, but rather what actual input voltages can be effectively rejected at the specific frequencies representing the

carriers of the undesired signals. And it is desirable to know these values for more than three channels either side, since in many cases the input voltages from near-by powerful stations are great enough to be roublesome even when they are 50 kc away from the desired station.

In general, the resonance curve is not symmetrical. But the departure from symmetry is negligibly small on the channels near resonance. For the fifth channel above, as against the fifth channel below, the difference is less than 10 per cent even with very good coils. Moreover, this dissymmetry is predictable, with normal circuits, so that given one side of the curve, the other may be drawn without measurement.

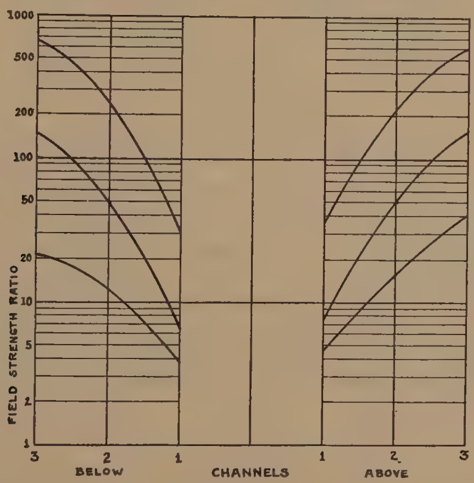

Fig. 3—Usual selectivity curves, with central portion omitted.

ment. In general, the channels below resonance will show a lower permissible input voltage for satisfactory rejection.

It is therefore suggested that a more accurate and informative presentation of selectivity data would be secured by drawing curves between radio frequency and the input voltage corresponding to acceptable rejection for each of the first five channels below resonance. If the selectivity is constant, these curves will be horizontal lines. Any departure from uniformity may be measured by the slope of the lines. Such a set of curves have been drawn in Fig. 4 for a well-known standard commercial tuned radio-frequency receiver.

In the light of our present knowledge we may see that the superheterodyne method was a very clever and satisfactory answer to two problems; (1) the necessity for securing greater amplification without danger of oscillation, and (2) the apparent fact, reiterated in print as

late as last year, that the selectivity of tuned circuits necessarily varied with frequency, becoming progressively worse as the frequency was increased. If, due to the researches which have been described in an-

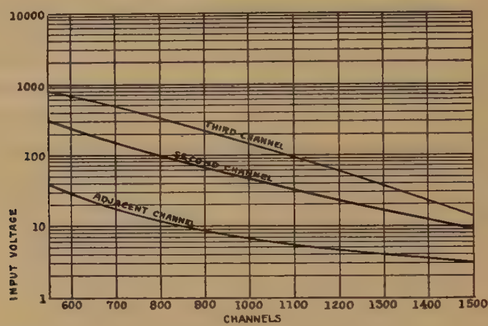

Fig. 4—Suggested form of selectivity curves.

other paper,[9] we are about to acquire means for definitely controlling the selectivity characteristic of our circuits, then this latter problem has a new and perhaps much more satisfactory answer.

Appendix

Comparison of Selectivity Curves and Fidelity Curves

1. The ordinates of the two curves as drawn are

$$y_s = E_\omega/E_R \qquad (1) \qquad\qquad y_f = V_p/V_{400} \qquad (2)$$

where,

y_s = ordinate of any point on selectivity curve
y_f = ordinate of any point on fidelity curve
E_ω = r-m-s value of modulated input off resonance
E_R = r-m-s value of modulated input at resonance
V_p = r-m-s value of audio output at frequency $p/2\pi$
V_{400} = r-m-s value of audio output at frequency 400

which is the reference point for the fidelity curve.

2. The values of y_s are greater than unity, whereas, in general, the values of y_f are less than unity. In order to bring them into agreement, we shall invert y_s, writing

$$y_s = E_R/E_\omega. \qquad (3)$$

We shall now determine the conditions under which $y_s = y_f$ for any displacement from resonance in the selectivity measurement and the

[9] W. J. Polydoroff, "Magnetic cores for high frequencies," also presented before Rochester Fall Meeting, November 9, 1931. Unpublished to date.

corresponding audio-frequency modulation in the fidelity measurement.

3. The r-m-s value of any input voltage is

$$E = er \qquad \text{where} \qquad r = \frac{1}{\sqrt{2}}\sqrt{1 - \frac{m^2}{2}} \tag{4}$$

e being the carrier amplitude
m = degree of modulation

and is independent of the frequency of the carrier or the modulation.

4. The r-m-s value of the audio output current is

$$V = adme/\sqrt{2} \quad \text{for linear detectors} \tag{5}$$

and,

$$V = adme^2/\sqrt{2} \quad \text{for square-law detectors} \tag{6}$$

neglecting second-order terms. In the above

a = total effective amplification at resonance
d = detection coefficient.

We shall assume that d is constant for all inputs, but a will have to be modified for off resonance frequencies by a factor representing the attenuation.

5. If $k_p\, a$ is the effective amplification for a frequency $\omega_r/2\pi$ modulated at $p/2\pi$ cycles, the effective values of the output currents are such that[10]

$$\text{(Fidelity)} \quad V_p/V_{400} = k_p a/a = k_p \qquad (k_p < 1) \tag{7}$$

for either linear or square law detectors.

6. If $K_\omega a$ is the effective amplification for a frequency $\omega/2\pi$ which is $p/2\pi$ cycles above resonance and modulated with a frequency of 400 cycles, then the effective values of the radio frequency inputs are such that[10]

$$E_R/E_\omega = e_R/e_\omega \tag{8}$$

e_R being the peak carrier amplitude before modulation, there being the same degree of modulation at both radio frequencies.

The corresponding output voltage ratio is

$$\text{(Selectivity)} \quad V_R/V_\omega = ae_R/k_\omega\, a\, e_\omega \quad \text{(Linear detector)} \tag{9}$$

but the output is held constant and $V_R = V_\omega$, whence

$$e_R = k_\omega e_\omega$$

$$e_R/e_\omega = k_\omega \qquad (K_\omega < 1) \tag{10}$$

[10] This assumes an audio amplifier of flat frequency characteristic.

and,

$$E_R/E_\omega = e_R/e_\omega = K_\omega = V_p/V_{400} = k_p, \quad \text{or} \quad k_p a = k_\omega a, \tag{11}$$

if the two readings are to be the same.

This requires that the total effective radio-frequency amplification shall be the same for

1. A resonant signal modulated at $p/2\pi$ cycles.
2. A nonresonant signal, $p/2\pi$ cycles off resonance modulated at 400 cycles.

7. In order to determine the conditions under which this will be true, we shall note that the detector will act upon any voltages applied to its grid, and we will determine what these voltages will be for the two signals under consideration.

8. For the fidelity signal we have at the input

$$e \sin \omega t + \frac{m}{2} e \cos (\omega - p)t + \frac{m}{2} e \cos (\omega + p)t. \tag{12}$$

Now if k_1 is the ratio of effective amplification at either of the side frequencies (assuming a symetrical curve) then on the detector grid we have

$$ae \sin \omega t + k_1 a \frac{m}{2} e \cos (\omega - p)t + k_1 a \frac{m}{2} e \cos (\omega + p)t \tag{13}$$

and the rectified r-m-s value will be

$$V_p = da \times k_1 a \times m \times e/\sqrt{2} = da^2 k_1 me/\sqrt{2}. \tag{14}$$

9. For the selectivity signal we have at the input

$$\begin{aligned} &\frac{e}{K_\omega} \sin (\omega + p)t + \frac{m}{2K_\omega} \cos \left(\omega + p - \frac{400}{2\pi}\right)t \\ &+ \frac{m}{2K_\omega} e \cos \left(\omega + p + \frac{400}{2\pi}\right)t \end{aligned} \tag{15}$$

and if $k_2 k_3$ are the effective amplification ratios for the frequencies $(\omega + p - 400/2\pi)$ and $(\omega + p + 400/2\pi)$ respectively, then on the detector grid we have

$$\begin{aligned} &\frac{ak_1 e}{K_\omega} \sin (\omega + p)t + \frac{ak_2 me}{2K_\omega} \cos \left(\omega + p - \frac{400}{2\pi}\right)t \\ &+ \frac{ak_3 me}{2K_\omega} \cos \left(\omega + p + \frac{400}{2\pi}\right)t \end{aligned} \tag{16}$$

and the rectified r-m-s value will be

$$V_\omega = \frac{d \times \dfrac{ak_1}{K_\omega}\left(\dfrac{ak_2m}{2K_\omega} + \dfrac{ak_3m}{2K_\omega}\right)e}{\sqrt{2}} \tag{17}$$

$$= \frac{da^2mk_1e(k_2 + k_3/2K_\omega)}{\sqrt{2}}. \tag{18}$$

Now $V_\omega = V_{400} = V_p/k_p$
and if

$$\frac{da^2k_1me}{k_p\sqrt{2}} = \frac{da^2k_1me(k_2 + k_3/2K_\omega)}{\sqrt{2}} \tag{19}$$

then,

$$k_p = 2K_\omega/k_2 + k_3 \tag{20}$$

but if $k_p = k_\omega$
then,

$$k_2 + k_3 = 2$$

and since neither k_2 or k_3 can be greater than unity, the condition can only be met when there is no attenuation and $k_2 = k_3 = 1$.

Thus the selectivity curve and the fidelity curve will not agree when there is any substantial attenuation in the audio range.

Note that this result would not be altered by a square-law detector.

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ELECTRICAL INTERFERENCE IN MOTOR CAR RECEIVERS*

By
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Summary—*In the high tension and low tension ignition circuits of present-day motor cars there are three sources of high-frequency transients in time and space. In the lighting generator there is another. These radiations and their reduction to acceptable levels to avoid pick-up by the supply and antenna leads to the receiver and the best form of antenna are discussed.*

Introduction

Since the installation of the first motor car radio, interference originating in the circuits necessary for the proper functioning of the car as a motor vehicle has been serious. With the advent of motor car receivers having sensitivities of less than 5 microvolts these effects have become even more bothersome.

It is the purpose of this paper to discuss the nature of these disturbances and the practical means of reducing them to such levels that their effects in the loud speaker are inaudible. We all dream of that radio Utopia where noises from all sorts of electrical interference are eliminated, but for the present, let us assume that circuits outside of the car itself are beyond our control. Practically all motor vehicles using radio are equipped with lighting generators and battery ignition systems. The sources of interference with a magneto ignition system are quite similar to those with a battery system. The battery system will be discussed as being typical.

Sources of Interference

The interference originates in spark discharges

(a) at the spark plugs,
(b) at the high tension distributor or at poorly connected leads in its circuit,
(c) at the low tension interrupter, or
(d) at the generator brushes.

These discharges produce transients consisting of an infinite series of space and time harmonics[1] which are coupled to the receiver either by radiation, by conduction along the car wiring and other insulated

* Decimal classification: R430. Original manuscript received by the Institute, February 3, 1932. Presented before New York Meeting, February 3, 1932.

[1] L. V. Bewley, "Transient oscillations of mutually coupled windings," paper presented before A.I.E.E., January 25–29, 1932.

conductors, or by both.[2] They recur at an audio rate, and are of sufficient intensity to be picked up by the antenna even though the supply leads to the receiver are filtered or shielded.

The pattern of the fields produced by the discharges is exceedingly intricate because of the peculiar space arrangement of the car body and wiring. It varies with the firing of each cylinder, since the high tension spark plug cables are not alike.

In some cases the voltage developed in a neighboring circuit by the primary discharge is sufficient to produce a secondary spark which is in turn a source of radiation. If corona appears on any part of the high tension wiring, this may also cause interference.[3]

Frequencies

The frequencies of the discharges are determined by the distributed inductances and capacitances of the leads coupled to the various sources. Since the leads are short and well insulated, these distributed constants are small and the frequency spectrum of the most important components of the radiation is well above the broadcast band.

Short-wave experimenters are acquainted with the fact that in the short-wave bands the radiation from passing motors is very troublesome. An amateur who was particularly interested found that the radio disturbance from a Model T Ford was most noticeable at a wavelength of about five meters.

The author found standing waves on the low tension leads of an ignition coil during a crude laboratory test a number of years ago. A spark gap had been placed across the primary leads close to the coil. Sparks here jumped a 1/32-inch gap. At a distance of two feet from the coil no spark could be produced across the smallest physical gap between the same leads. Two feet must have been an appreciable portion of a half wavelength.

It was also observed in checking interference due to commutator sparking that by-passing a lead from one of the brushes with a small condenser from one point to ground might reduce the interference, while the same condenser moved along the wire only a foot might increase it.

These recurrent short-wave impulses may produce an audio output in a receiver turned in the broadcast band

(a) by reaching the last detector, in spite of circuit attenuation

(b) by beating each other at the frequency setting of the receiver

[2] James G. Allen, "Radio interference," Proc. I.R.E., **17**, 882; May, 1929.
[3] F. O. McMillan, "Radio interference from insulator corona," *Jour. A.I.E.E.*, **51**, 3; January, 1932.

and at a sufficiently high level to be demodulated in a tube preceding the normal detector, or

(c) by actual extension into the broadcast frequency band.

Shielding

An obvious means of reducing the radio interference in any motor installation fitted with spark ignition is by shielding the complete electrical system. This method is standard practice in airplanes[4] and has been successfully applied to motor cars.[5]

Complete shielding, however, is impractical in stock motor cars on account of the complexity of wiring and the cost.

Shielding does not reduce the energy of the disturbance but merely confines it within the enclosure of the shield. Partial shielding may even increase the radiation from the remaining unshielded wiring by resonating parts of the circuit at frequencies nearer the broadcast band due to the added capacitance of the covering to ground. Added capacitance to ground may also, in some cases, render the ignition system unreliable.

A better remedy is to reduce the disturbances at their sources below troublesome levels without impairing the operation of the vehicle.

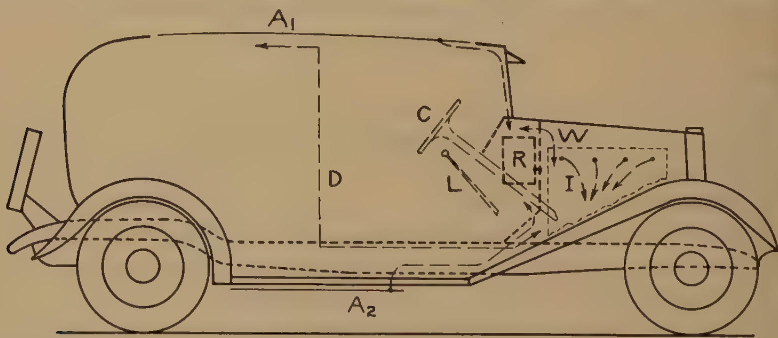

Fig. 1

Relative Location of the Circuits

Fig. 1 shows schematically the location of the circuits which must be considered. The heavy lines indicate the car body, usually of metal, and the receiver chassis *R*, which are considered as the reference ground. A_1 and A_2 are alternative antennas. All of the initial disturbances occur within the engine compartment. *I* is the high tension

[4] H. Diamond and F. G. Gardner, "Engine ignition shielding for radio reception in aircraft," Proc. I.R.E., 18, 840; May, 1930.

[5] Paul O. Farnham, "A broadcast receiver for use in automobiles," Proc. I.R.E., 18, 321; February, 1930.

ignition wiring, the principal source of disturbance; W, any wiring from the engine compartment to the receiver or space near the receiver; D, any long leads coupling the antenna to the source. The primary breaker or interrupter and the lighting generator (not shown) are also located in the engine compartment, and, as far as general position is concerned, may be considered with the high tension circuits. The steering column C, and the gear shift lever L, are not above suspicion in certain types of cars.

Antennas of the above types have almost no inductance and have capacitances of from 100 to 300 $\mu\mu$f. They are practically nondirectional.

The antenna in the roof is usually of wire screen carefully insulated and covering as large an area as possible. Its effective height depends on its configuration with respect to the car.

An antenna under the car is usually an insulated metal plate as near the ground as allowed by road clearance. In this case the signal pick-up is by the car body insulated by its tires. The antenna is placed in the field between the body and ground, and the voltage between the plate and the body is applied to the antenna lead.

In both types of antennas, the leads should be shielded by copper braid as far back as possible from the source of interference—the engine compartment. The braid should be well connected to the receiver chassis and prevented from grounding intermittently at other points.

The interference field is somewhat stronger above the car than in the shielded space beneath it and to the rear of the engine compartment. In this respect the antenna A_2 has an advantage over A_1.

Because of its large size, the roof antenna is usually more effective as a signal pick-up, but in cars not so equipped at the factory, cannot be installed without reupholstering the top.

A sizable plate beneath the car—or a pair of plates, one on each side of the car—coupled to the shielded line by a properly designed step-down transformer makes a very effective pick-up freer from interference than the roof type.

A very successful type of antenna installation has been made in the form of an insulated metal bow between rear mud guards over the tire carrier. This is still further from the source of disturbance but is not quite as well located for effective signal pick-up as either of the other types mentioned.

High Tension Ignition Circuits

By far the greatest intensity of interference is from the spark plugs.

Figs. 2 shows the circuits of a typical high tension battery ignition system. The car battery, which also supplies all of the other electrical

equipment on the car, feeds the primary winding of an ignition coil through a cam-operated interrupter, run at one half crank shaft speed.

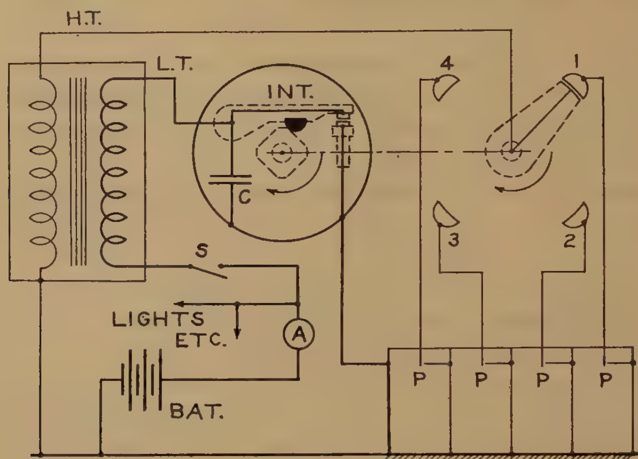

Fig. 2

The secondary winding of the coil is connected successively to the spark plugs through a rotating distributor switch arm or rotor, operated synchronously with the cam.

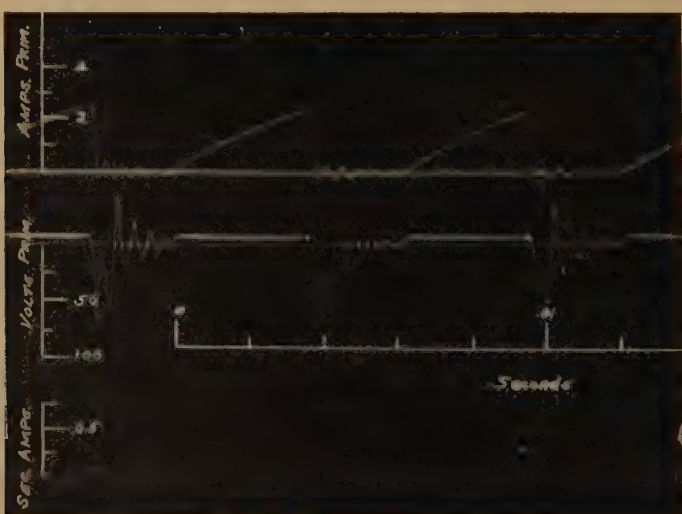

Fig. 3

The condenser C, across the interrupter contacts, aids in extinguishing the contact arcing and is of a size to resonate at a frequency

of from 2000 to 3000 cycles per second with the primary inductance of the coil.

Fig. 3 shows a low-frequency oscillogram of a typical battery ignition system. It will be noted that there is a comparatively large oscillatory coil voltage just after the interrupter opens. During the time secondary current flows the high tension winding is practically short-circuited and the frequency is of the order of 8000 cycles per second, while with the secondary open, the frequency is of the order of 2300 cycles per second. The voltages which it is possible to show by s ch an oscillogram are not those which cause interference, but, as will be shown later, are of importance in the proper functioning of the ignition system.

The successive periods in the ignition cycle are as follows:

(a) interrupter open—no current.
(b) interrupter closed—current building up.
(c) contacts start to open—primary current causes arc or spark at contacts.
(d) contact spark extinguished—start of low-frequency oscillation —common secondary cable rises in voltage.
(e) rotor gap voltage gradient allows breakdown—individual plug cable rises in voltage.
(f) plug gap breaks down—secondary ignition current flows.
(g) ignition current ceases—oscillatory primary energy finally dissipated.

While these periods follow each other at comparatively long intervals as viewed from a radio standpoint, the transition points between the last five involve sudden changes in dielectric fields and are causes of high-frequency radiations.

Fig. 4 is a very much exaggerated time diagram showing these periods and the troublesome successive transition points marked *W*, *X*, *Y*, and *Z*. Transition point *W* is associated with changes in the primary circuit and will be considered later.

Transition points *X*, *Y*, and *Z* are due to sudden changes in the secondary circuit and yield to the same treatment for the reduction of interference.

The distributed inductances and capacitances of the spark plug circuit are indicated very roughly in Fig. 5. It is impossible to represent them accurately because of the variations in the cable lengths and in the distances to engine block, hood, low tension leads, and to other high tension leads for the different spark plugs.

Just previous to ignition, the potential of the common distributor lead rises until the gradient across the rotor gap renders it conducting,

after which the individual lead assumes the same potential. At the instant of rotor breakdown, the stored energy in the field of the common lead is redistributed along the whole length of the lead to the plug. This

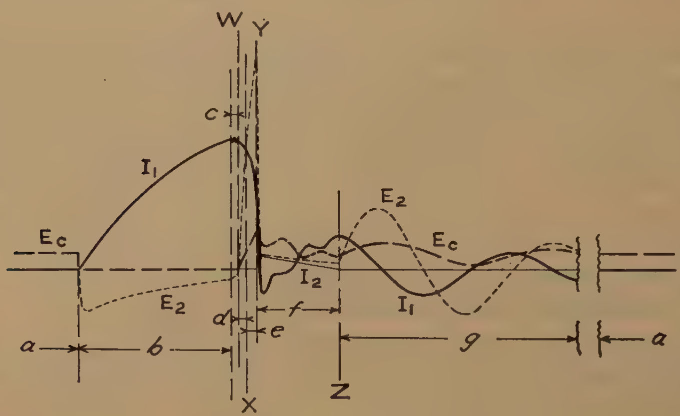

Fig. 4

sudden change initiates high-frequency transients which may be suppressed in the same way as the somewhat stronger transient at the spark plug which is now to be considered.

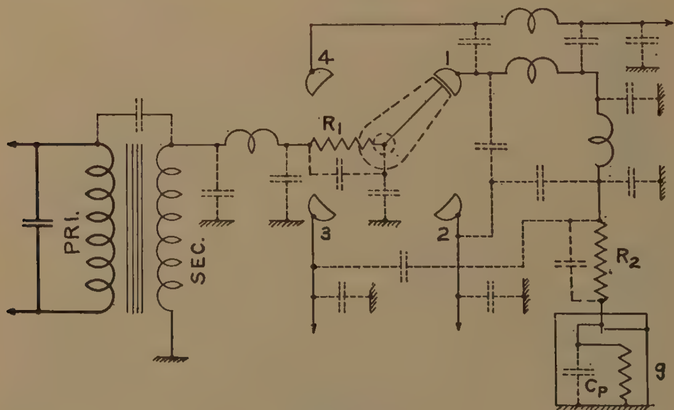

Fig. 5

At a critical voltage (about 6000 or 7000 volts), depending on the fuel mixture, the temperature, and the separation of the plug electrodes, a spark passes to ground at the plug, practically short-circuiting this end of the high tension lead. The stored energy in the complex

dielectric space field about the conductors all the way back to the coil is discharged and is the source of a transient of considerable power. This is reflected from the short-circuited plug and the coil at frequencies depending on the distributed constants. That the transient voltage is considerable, is evidenced by the fact that sparks may pass in cylinders not under compression if the leads to the plugs in these cylinders lie adjacent for any considerable distance to the one actually in the circuit.

Shielding only the high tension leads has the effect of increasing the capacitance to ground and of increasing the energy to be released in the high-frequency transient. Adding lumped series inductance changes the frequencies and may reduce the number of harmonics radiated, but does not decrease the energy, and can not be depended upon to eliminate the interference.

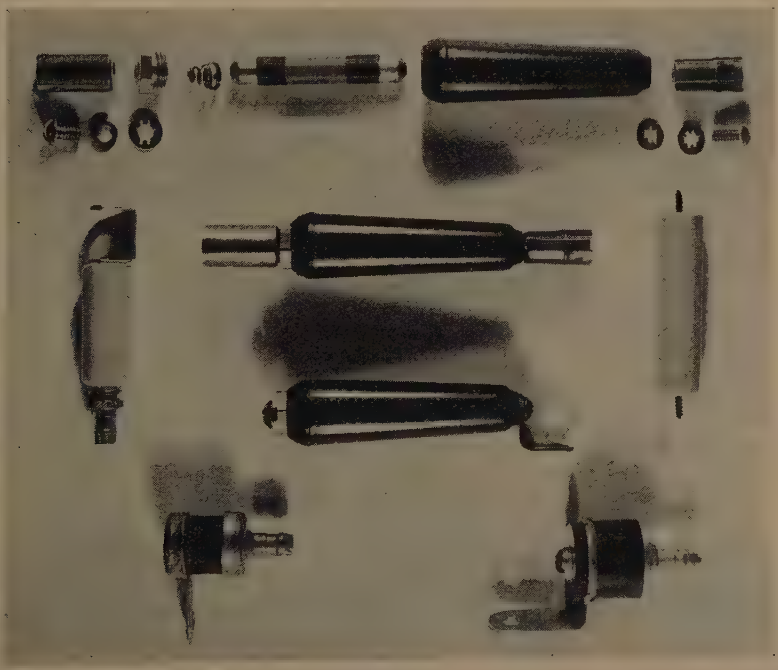

Fig. 6

Ignition Suppressors

The most effective means of reducing these radiations is to insert series resistance as close as possible to the sparking electrodes. A resistor close to the rotor in the common lead, and individual resistors in

the leads at the plugs are quite effective in increasing the damping of the circuit to a point where it is nonradiating. Fig. 6 shows several types of commercial suppressors, all of carbon mixtures. The long unit, shown with two types of terminals and also disassembled, has a bakelite case to protect it from grounding. The porcelain covered units are shown with two types of terminals, are sealed, and may not be disassembled. The units of larger diameter were of earlier manufacture and are discussed below.

These resistances must be capable of carrying high instantaneous currents without deterioration and must have low terminal capacitance to prevent coupling around them.

The first commercial resistors used as suppressors were of short length, of comparatively large cross section and with large terminals as shown. The resistance material was subjected to intense voltage gradients causing luminous destructive discharges from particle to particle through the binder. The large terminals added self-capacitance to the suppressor, and also to ground from the plug terminal, and were rather ineffective. In some cases flash over actually occurred between the terminals. A better suppressor was formed of a material of lower specific resistance, of greater length and of smaller cross section. The area of the terminal attached to the plug was reduced and the resistor located as near as possible to the plug.

Spark plugs are now being manufactured with the resistance material included inside the porcelain insulator. This construction still further reduces the self-capacity of the resistor and the exposure of the unprotected circuit.

It is predicted that when motor cars are factory equipped with radios, it will be found advantageous to include the common series resistance in the structure of the distributor rotor itself.

Unexpected Discharges

The high tension current easily passes through the cables from the coil to the plugs even though the wire in the cable does not actually make contact with the terminals. This often happens with installations which have seen several thousand miles of service, and adds an unexpected source of interference. All cables should be checked for continuity to terminals to eliminate these extra sparks.

The interrupter mechanism is often mounted on a plate movable by means of the spark-advance lever. Sometimes the whole distributor housing is turned for advance and retard. In such cases it is necessary to eliminate sparking through the oil and dirt between these metal surfaces by shunting the joint with flexible braid.

Effect of Suppressors on Ignition

Even the smallest spark at the plug electrodes is capable of producing ignition, but it may be produced only at a critical voltage. The equivalent low-frequency diagram of the circuit involved is shown in Fig. 7.

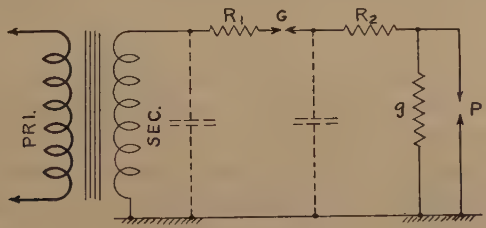

Fig. 7

g represents the conductance of the plug insulation and of any foreign deposit on its surface. At high engine temperatures, or at low temperatures if the porcelain is wet, this may be considerable. With large series resistances R_1 and R_2, the voltage developed across g during

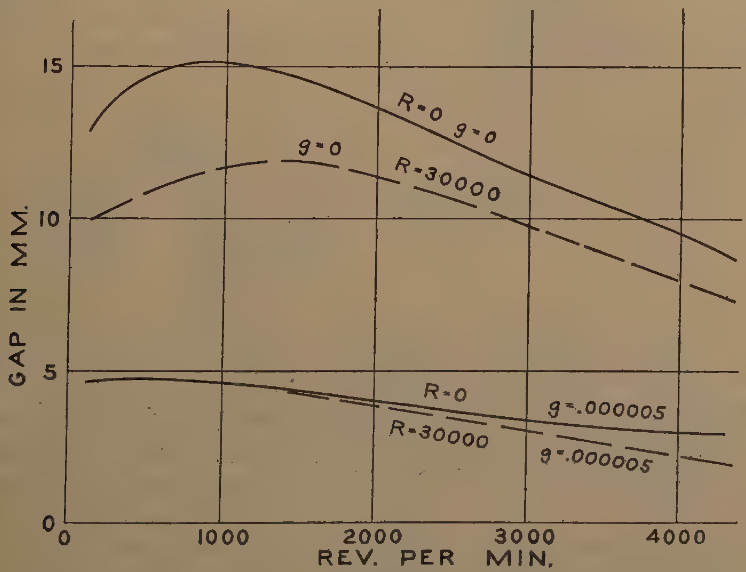

Fig. 8

the first half cycle of low-frequency oscillation may be insufficient to produce a spark. Typical variations in available plug voltage as measured with a standard three-electrode ignition test gap with several values of g and R are shown in Fig. 8. With excessive cable leakage or

cable capacitance to ground these voltages would be further reduced.

Resistances of the order of 15000 ohms are usually perfectly satisfactory from an ignition standpoint. These resistances are large enough to reduce the interference materially, but even for these values, the cables and plugs must be in good condition and the plug gaps must be as small as is consistent with fuel mixture, compression, and engine speed.

Low Tension Interference

Fig. 9 shows the primary circuit and the distributed constants involved in interference originating at the interrupter and previously mentioned as transition point W. (See Fig. 4.) The function of the condenser C_1 connected across the interrupter is to form a low-frequency oscillating circuit with the primary of the coil and to assist in extin-

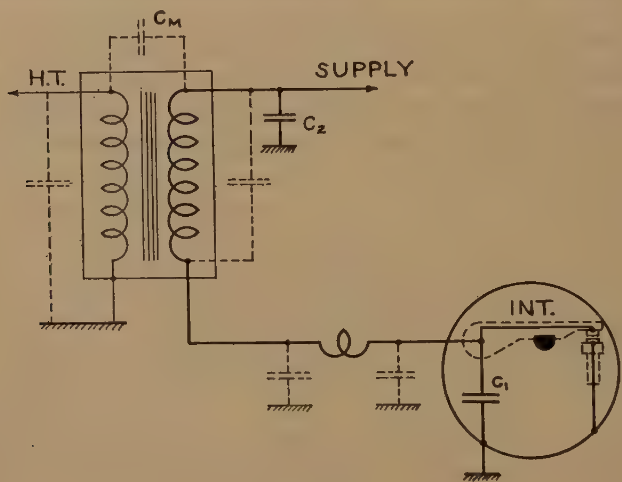

Fig. 9

guishing the arc or spark at the contacts. This capacitance must not be increased in size as the frequency of primary oscillation and consequently the induced voltage would be thereby reduced. Excessive capacitance across these leads also causes pitting of the tungsten contacts.

At low cam speeds it is possible that the contacts will be separated only a microscopic distance before the voltage builds up across them to a value causing a spark to again jump through the ionized space between them. This is true only if the secondary voltage is not yet sufficient to jump the plug electrodes. The contacts are then again practically short-circuited to ground, initiating high-frequency transients along the lead between them and the coil. These transients are re-

flected from the coil and are conducted along the low-tension wiring and radiated into space.

Resistance in series with the primary lead near the interrupter is not allowable since this would reduce the primary current below an operating value.

An additional condenser C_2 on the supply terminal of the coil effectively grounds the high-frequency impulses at this point and prevents their conduction along the supply lead. The lead from the coil to the interrupter should be as short as possible and not coupled to other conductors which might direct the impulses. In some cases it is advisable to shield this lead, carefully grounding it at the interrupter and coil housings. Shielding this lead is usually necessary if the coil is mounted on the bulkhead or under the instrument panel. The shielding and the condenser C_2, mentioned above, also serve to keep any interference from residual high tension disturbances which were not eliminated by the suppressors and which were by-passed to the low tension terminals through the capacitance of the windings, from passing further along the supply leads.

Both high tension and low tension disturbances are more easily eliminated if the coil is close to the distributor and no conductor between the coil and interrupter is led to the instrument panel. This connection, as well as the common high tension cable, should be as short as possible.

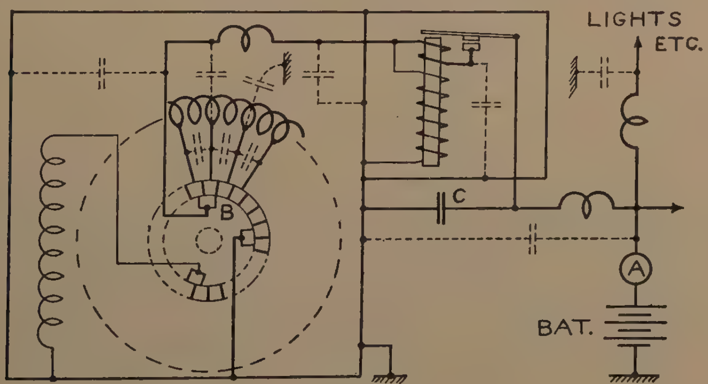

Fig. 10

Commutator Interference

The circuits of a typical third brush lighting generator are shown in Fig. 10. A spark at brush B originates transients which are conducted along the live lead through the generator cut-out to the car wiring from which they may be radiated. An effective means of eliminating this

source of disturbance is to by-pass the live lead as near as possible to the source. Condensers mounted on the cut-out cover are sometimes ineffective because of the resistance of the cover to ground. The ground connection should be as short as possible and securely bonded to the generator frame. The completed job should be checked at all engine speeds since brush sparking depends on both load and speed.[6]

If a dynamotor is used as a source of plate potential, the low voltage side may be treated in the same way as the lighting generator. The high voltage side must be filtered both for low-frequency commutator ripple and for the high-frequency transients originating at either set of brushes. In a dynamotor, spark disturbances at the low voltage brushes are coupled through the windings to the high-voltage commutator.

Since the current in the high voltage circuit is small, resistance-capacitance filters are quite as effective as inductance-capacitance filters.

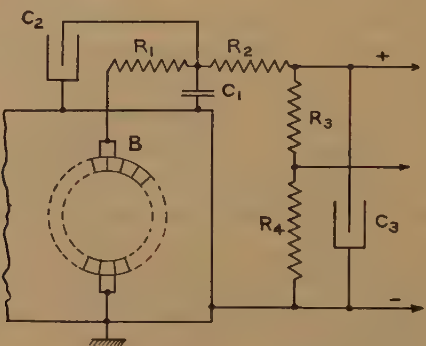

Fig. 11

Fig. 11 shows a typical filter for a commutator in a plate supply circuit. R_1 is as close to the brush as possible, and the first filter section is completed by high-frequency condenser C_1 having short leads. Condensers C_2 and C_3 (which may have long leads) with resistance R_2 form a π section to remove the low-frequency ripple. Resistors R_3 and R_4 serve as a potential divider for intermediate voltages.

Residual Interference

In spite of precautions taken as described, it is safe to say that in every case the disturbances are not completely eliminated but are only reduced in level. Conditions of coupling and radiation vary widely between different models of cars and even between chasses which are sup-

[6] R. E. Hellmond and L. R. Ludwig, "Commutation considered as a switching phenomenon," paper presented before A.I.E.E., January 25–29, 1932.

posedly identical. Where the engine is mounted on rubber and the connections from the car body to the frame vary in resistance or actually fail to make contact, the complex high-frequency field is radically changed. Long common returns for high- and low-frequency circuits are often a source of trouble. It is therefore advisable to filter or shield the supply leads entering the receiver. Since the filaments must be supplied by the same battery which is connected to the devices causing the interference, shielding the filament leads is usually ineffective unless both leads and shield are carried directly to the battery terminals. These leads may remain entirely unshielded if a choke and condenser filter is provided where the live lead enters the grounded receiver chassis.

The leads from the B battery or the B eliminator may remain unshielded if they are not closely coupled to interference circuits and if a by-pass condenser is used where each lead enters the receiver housing.

Interference tests are usually made by listening for noise in the loud speaker with the receiver adjusted to full sensitivity but in the absence of a modulated carrier. This should be done in a location where the external interference is low. The engine hood should be closed and latched to prevent other than normal radiation from the engine compartment.

Procedure in Installation

In making a motor car radio installation it is well to proceed in the following manner:

(a) Install the receiver chassis, speaker, and accessories. Use a shielded antenna lead and make sure that both the chassis and shielding braid are carefully grounded.

(b) Check the ignition system for the condition of the spark plugs and the interrupter contacts. Make sure that all high tension cables actually contact with the terminals at the distributor, plugs, or coil. Replace all leaky high tension cables.

(c) Connect the rotor and spark plug suppressors, the generator condenser, and the condenser on the supply side of the coil. Make sure that the resistors are close to the proper terminals and keep the condenser leads short.

(d) If the coil supply lead passes through the same conduit with the high tension cables move it to a position where it will be coupled to them as little as possible.

(e) Make sure that the interrupter mechanism is actually grounded —if necessary shunt it to the engine frame.

If interference still exists proceed in the following order:—

(f) If the coil is far from the distributor, move it if it is allowed.

(g) If the coil must remain remote from the distributor, shield the lead from the coil to the interrupter and ground the metal braid to the coil and the distributor housings.

(h) Be sure that the coil housing is well grounded to the engine block. If it is still mounted on the bulkhead, ground it through a flexible braided lead.

(i) Clamp all the low voltage wiring as close to the car frame as possible.

(j) Shield the 6-volt supply leads to the receiver and carry them back to the battery terminals.

(k) Check the interference with the dome light leads disconnected as near the source of interference as possible. If this reduces the interference insert a filter in these leads.

(l) Check the grounding of the steering column. If necessary add a flexible copper braid between the tube and the car frame.

(m) If the common high tension lead is long, shield it with copper braid, grounding the braid as often as possible along its length.

(n) Try other logical expedients suggested by the particular installation.

Conclusions

From the above it is seen that electrical interference originating in motor cars is quite similar to other better known applications of high-frequency phenomena. The elimination of all interference is limited by definite requirements of the original electrical system of the car. A good installation may be made in most cases by following definite rules. For those stubborn cases, for which no cure seems adequate, the problem should be tackled by a trained radio mechanic, and not by one who is skilled only in the mechanics of automobiles.

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TABLES OF NORTH ATLANTIC RADIO TRANSMISSION CONDITIONS FOR LONG-WAVE DAYLIGHT SIGNALS FOR THE YEARS 1922–1930*

By

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The following tables represent daylight transmission conditions between Europe and the northeastern United States for wavelengths between 13,000 and 20,000 m (15–23 kc). These are derived from signal intensity measurements made in Washington on a number of long-wave European transmitting stations averaged according to a method previously described.[1] The measurements in Washington are made at such times that daylight conditions exist over the whole of each of the signal paths.

The errors of the averaged values of signal field intensity as given in the tables are estimated not to exceed ±25 per cent in 1922, ±20 per cent in 1923, ±15 per cent in 1924 and 1925, and ±10 per cent from 1926 to 1930.

In issuing these tables, the author wishes to acknowledge his indebtedness to his assistants, E. B. Judson, who has taken most of the field strength observations, and S. E. Reymer, who has performed the necessary calculations.

TRANSMITTING STATION DATA

Station	Approximate Frequency and Wavelength f	λ
	kc	m
Bordeaux, France (FYL)	15.7	19,100*
Nauen, Germany (DFW)	23.1	13,000
Ste. Assise, France (FTT)	21.0	14,300
Ste. Assise, France (FTU)	15.2	19,700
Nauen, Germany (DFY)	16.6	18,100
Rugby, England (GBR)	16.0	18,700
Rome, Italy (IRB)	20.8	14,400
Kootwijk, Holland (PCG)	16.8	17,800

* Before June, 1923, the wavelength of FYL was 23,400 m (12.8 kc).

* Decimal classification: R113.2. Original manuscript received by the Institute, November 28, 1931. Publication approved by the Director of the Bureau of Standards of the U. S., Department of Commerce.

[1] Proc. I.R.E., 19, 1615, 1931.

NORTH ATLANTIC DAYLIGHT RADIO TRANSMISSION CONDITIONS
1922

Microvolts per Meter.

Date	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	33	29	51	23	34	35	31	—	36	—
2	27	—	46	34	—	30	35	30	19	27
3	26	36	48	25	51	29	—	21	43	—
4	25	32	33	30	—	31	—	36	22	35
5	—	21	30	—	35	40	36	27	—	30
6	31	36	12	—	48	—	36	26	32	27
7	23	42	—	60	40	36	30	39	34	29
8	33	33	34	34	32	26	24	—	14	18
9	39	—	48	20	—	26	37	34	13	16
10	39	39	55	—	34	29	—	34	9	—
11	28	48	43	—	33	30	35	30	6	14
12	—	59	39	23	38	33	33	32	—	21
13	26	70	32	21	43	—	51	26	16	—
14	30	11	—	24	35	33	40	—	18	30
15	31	31	34	35	34	28	32	—	10	18
16	34	—	25	25	—	32	33	43	13	15
17	39	27	26	27	40	34	—	30	22	—
18	28	32	—	—	—	27	18	41	9	21
19	—	41	21	22	44	25	27	—	—	15
20	20	47	7	13	34	—	32	39	10	27
21	22	40	—	43	26	38	44	38	—	19
22	30	54	—	32	30	30	28	—	7	26
23	38	—	38	27	—	28	50	34	7	28
24	45	57	—	45	—	31	—	—	26	—
25	28	51	77	—	34	34	30	26	27	—
26	—	47	44	55	42	34	39	21	—	19
27	27	43	46	27	27	—	32	21	34	26
28	34	42	—	26	—	30	34	4	25	9
29	50	43	47	47	42	35	29	—	21	13
30	32	—	—	34	—	—	32	17	—	17
31	16		36		29	—		26		—
Monthly Average	31	40	38	31	37	31	34	29	20	22

— No observation.
Stations averaged: Nauen, DFW; and Bordeaux, FYL.

NORTH ATLANTIC DAYLIGHT RADIO TRANSMISSION CONDITIONS
1923

Microvolts per Meter.

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	—	21	35	—	37	38	—	42	87	55	39	8
2	11	31	38	—	26	26	44	37	—	51	22	—
3	35	28	45	35	11	—	52	52	—	45	38	—
4	38	—	—	65	5	36	—	35	27	55	—	—
5	45	33	43	30	28	—	45	—	65	56	25	6
6	27	33	23	45	—	30	35	35	52	23	37	9
7	—	53	32	47	32	33	22	32	46	—	37	11
8	37	40	29	—	19	41	—	—	63	39	59	12
9	48	38	30	29	31	16	37	—	—	54	38	—
10	34	39	28	37	24	—	27	—	67	52	41	16
11	39	—	—	40	50	28	35	35	75	50	—	16
12	29	32	26	38	50	23	43	—	64	65	15	14
13	40	25	24	47	—	43	33	37	54	52	34	12
14	—	34	28	28	15	33	19	40	60	—	38	12
15	37	45	29	—	18	45	—	37	55	32	39	18
16	34	35	25	35	29	29	19	38	—	29	33	—
17	38	31	40	17	49	—	67	37	39	35	42	23
18	25	—	—	26	34	42	48	37	34	45	—	16
19	35	31	40	26	53	48	48	—	45	37	30	—
20	18	26	39	36	—	43	61	48	40	33	62	—
21	—	29	42	29	—	57	37	38	33	—	25	14
22	37	—	38	—	48	35	—	30	32	27	40	7
23	48	35	45	24	48	40	65	39	—	32	33	—
24	44	30	42	36	45	—	50	31	37	45	22	15
25	36	—	—	35	59	43	48	29	54	34	—	—
26	29	28	62	52	48	29	79	—	45	33	31	26
27	32	59	54	45	—	43	—	46	40	35	25	12
28	—	52	41	58	45	35	—	39	45	33	13	22
29	40		52	—	39	41	—	41	45	37	—	23
30	37		52	52	—	34	55	29	—	37	14	—
31	35		48		26		48	42		32		19
Monthly Average	35	35	38	38	35	36	44	38	50	41	33	15

— No observation.
Stations averaged: Nauen, DFW; and Ste. Assise, FTT.

NORTH ATLANTIC DAYLIGHT RADIO TRANSMISSION CONDITIONS
1924

Microvolts per Meter

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	—	61	23	26	18	—	34	30	—	44	22	29
2	20	45	—	31	20	34	29	38	33	40	—	22
3	28	—	41	47	15	25	—	—	43	42	21	22
4	30	18	39	39	—	32	—	30	32	44	20	28
5	30	32	51	46	30	37	—	38	30	—	17	37
6	—	31	39	—	31	30	—	49	—	40	16	49
7	36	30	43	45	41	24	25	22	—	39	15	—
8	25	46	24	39	19	—	—	26	55	42	21	32
9	33	30	—	42	26	14	23	29	45	48	—	—
10	40	—	40	45	27	30	23	—	35	47	29	35
11	20	41	50	29	—	24	33	29	45	36	21	21
12	35	22	31	38	25	29	30	26	49	—	24	—
13	—	34	35	—	27	24	—	27	49	36	18	12
14	21	16	37	22	24	32	37	24	—	46	18	—
15	27	19	27	26	23	—	28	33	41	38	15	18
16	20	28	—	20	22	44	27	27	48	37	—	11
17	23	—	38	30	23	13	29	—	40	27	29	24
18	18	27	33	36	—	26	47	33	44	40	18	20
19	16	35	28	23	27	28	39	38	41	—	33	22
20	—	19	23	—	33	34	—	42	43	29	22	16
21	23	45	28	22	25	31	34	26	—	33	16	—
22	24	—	33	19	35	—	27	—	39	37	17	26
23	26	51	—	31	40	37	34	33	42	33	—	37
24	28	—	30	32	27	26	32	—	50	34	18	24
25	22	34	31	33	—	32	30	24	43	42	17	—
26	31	37	24	31	33	22	31	27	46	—	22	10
27	—	43	35	—	36	38	—	42	35	13	—	22
28	26	45	32	30	30	29	42	28	—	18	20	—
29	34	28	25	18	18	—	28	29	29	26	15	20
30	32		—	11	—	38	35	30	41	26	—	22
31	74		34		34		31	—		25		21
Monthly Average	29	34	34	31	27	29	32	31	42	36	20	24

— No observation.
Stations averaged: Nauen, DFW; Bordeaux, FYL; Ste. Assise, FTT and FTU.

NORTH ATLANTIC DAYLIGHT RADIO TRANSMISSION CONDITIONS
1925

Microvolts per Meter

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	—	—	—	40	28	37	43	40	46	30	—	27
2	24	24	39	27	35	31	21	—	56	34	30	27
3	22	20	49	27	—	37	—	41	51	30	—	24
4	—	32	—	24	—	42	—	39	27	—	39	33
5	—	21	37	—	31	34	—	40	38	38	44	19
6	—	23	35	26	34	38	43	44	—	40	—	—
7	20	25	26	32	28	—	34	46	—	41	23	30
8	20	—	—	32	36	27	38	54	45	44	—	52
9	28	—	28	—	33	33	51	—	63	48	21	32
10	20	23	27	41	—	31	33	45	46	43	36	33
11	—	18	32	29	32	35	35	46	56	—	41	28
12	16	31	27	—	47	28	—	47	44	36	33	31
13	20	25	26	46	41	36	30	50	—	45	37	—
14	22	24	33	28	32	—	39	35	50	46	37	27
15	24	—	—	44	30	41	36	35	48	51	—	35
16	35	15	31	37	32	29	23	—	22	28	34	25
17	26	22	27	37	—	32	37	21	49	24	30	28
18	41	13	28	25	42	44	30	44	48	—	29	38
19	26	34	25	—	53	31	—	40	43	38	30	42
20	24	—	33	31	31	35	32	34	—	24	47	—
21	25	32	37	24	45	—	33	33	24	35	30	31
22	12	—	—	26	34	31	37	—	42	40	—	27
23	37	—	36	22	41	32	38	—	54	39	26	41
24	53	34	31	25	—	30	38	50	42	37	34	31
25	—	38	35	24	32	42	39	51	43	—	29	—
26	28	42	27	—	33	34	—	67	41	34	—	—
27	25	38	32	—	28	33	44	60	—	38	23	—
28	28	36	21	—	25	—	—	44	46	44	30	34
29	33		—	43	28	40	26	57	54	42	—	35
30	22		22	40	—	37	33	—	36	37	33	48
31	23		28		—		42	50		28		27
Monthly Average	26	27	31	32	35	35	36	45	45	37	33	32

— No observation.
Stations averaged: Nauen, DFW and DFY; Bordeaux, FYL; and Ste. Assise, FTT and FTU.

NORTH ATLANTIC DAYLIGHT RADIO TRANSMISSION CONDITIONS
1926

Microvolts per Meter

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	—	50	52	32	41	44	39	—	39	46	38	36
2	58	45	46	33	—	37	30	36	40	34	33	29
3	—	38	49	27	36	42	26	35	41	—	38	34
4	37	40	42	—	53	36	—	43	47	30	22	—
5	47	48	37	28	47	31	19	36	—	36	26	—
6	35	36	44	35	47	—	24	48	—	31	17	34
7	25	—	—	28	43	34	—	37	34	42	—	33
8	40	42	46	36	39	43	35	—	39	39	20	30
9	30	31	49	44	—	46	35	44	43	34	24	33
10	—	32	61	24	38	31	34	41	50	—	32	25
11	33	42	45	—	41	30	—	42	44	26	24	32
12	31	41	39	43	45	35	31	32	—	36	30	—
13	41	42	48	41	46	—	31	28	59	24	22	25
14	43	—	—	39	50	21	33	34	46	24	—	30
15	28	33	46	46	57	43	34	—	64	—	29	27
16	43	37	27	—	—	54	32	35	42	42	21	36
17	—	31	38	36	55	50	36	41	44	—	25	31
18	32	36	40	—	47	45	—	38	61	41	35	—
19	43	29	32	57	42	59	35	32	—	—	20	—
20	39	31	33	51	37	—	38	28	—	—	17	34
21	24	—	—	57	52	45	41	28	34	34	—	30
22	22	—	—	56	55	33	32	—	48	37	23	27
23	43	55	37	61	—	38	37	43	51	36	23	33
24	—	49	35	52	40	32	33	28	47	—	21	34
25	—	57	34	—	43	39	—	25	48	42	—	—
26	53	48	44	33	37	27	39	40	—	46	21	—
27	38	63	53	55	45	—	42	42	52	32	—	31
28	42	—	—	52	37	42	40	37	41	44	—	29
29	61		25	51	44	38	37	—	—	29	52	26
30	57		34	53	—	37	34	30	—	29	34	32
31	—		32		—		37	28		—		28
Monthly Average	39	42	41	43	45	39	34	36	46	35	27	31

— No observation.

Stations averaged: Nauen, DFW and DFY; Bordeaux, FYL; Ste. Assise, FTT and FTU; and Rugby, GBR.

NORTH ATLANTIC DAYLIGHT RADIO TRANSMISSION CONDITIONS
1927

Microvolts per Meter

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	—	28	—	50	—	61	56	41	55	45	42	37
2	—	26	23	55	45	61	—	47	55	—	36	32
3	37	28	32	68	39	54	—	58	40	45	29	40
4	33	25	34	53	35	59	—	51	—	49	41	—
5	33	29	28	39	37	—	47	48	—	45	47	41
6	29	—	—	44	29	60	55	45	58	52	—	33
7	26	31	32	45	36	47	35	—	57	47	28	34
8	48	22	30	49	—	49	49	49	51	41	27	25
9	—	29	32	39	38	52	58	54	50	—	23	27
10	41	41	33	29	—	46	—	59	46	48	38	30
11	36	30	39	47	34	42	53	47	—	45	31	—
12	40	33	39	41	73	—	48	57	40	52	29	30
13	38	—	—	41	46	47	45	47	38	59	—	25
14	31	31	36	38	—	43	39	—	49	137	48	32
15	33	17	36	42	—	39	—	38	50	59	37	37
16	—	35	32	48	—	46	32	51	50	—	19	32
17	40	29	44	—	—	43	—	51	61	39	16	43
18	36	16	45	45	58	45	—	41	—	33	29	—
19	35	22	43	42	45	—	47	61	49	65	34	35
20	32	—	—	43	42	24	64	—	44	37	—	35
21	29	29	29	49	41	46	32	—	55	49	35	47
22	24	—	46	34	—	52	53	64	38	39	42	32
23	—	35	56	43	21	54	49	50	39	—	33	38
24	54	32	44	—	27	51	—	54	49	51	—	—
25	39	34	38	51	30	45	57	37	—	49	49	—
26	31	32	43	43	47	—	46	48	72	44	37	—
27	34	—	—	47	34	68	—	46	47	51	—	60
28	34	33	59	—	38	55	47	—	49	49	26	41
29	28		47	33	—	46	52	50	59	37	35	43
30	—		55	35	—	47	67	43	51	—	28	—
31	34		62		44		—	50		61		47
Monthly Average	35	29	40	44	40	49	49	50	50	51	34	36

— No observation.
Stations averaged: Nauen, DFW and DFY; Bordeaux, FYL; Ste. Assise, FTT and FTU; and ugby, GBR.

NORTH ATLANTIC DAYLIGHT RADIO TRANSMISSION CONDITIONS
1928

Microvolts per Meter

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	—	43	—	—	—	37	—	—	34	57	28	35
2	—	36	46	—	38	39	—	34	—	41	29	—
3	50	33	—	40	31	—	45	36	—	32	31	40
4	51	26	—	33	38	48	—	31	52	37	—	41
5	29	—	32	44	32	39	45	—	43	36	29	54
6	34	29	35	31	—	41	36	37	46	35	31	55
7	31	21	28	43	50	47	37	49	35	—	26	41
8	—	31	31	—	39	38	—	33	50	26	20	49
9	26	30	34	44	43	46	40	23	—	61	36	—
10	30	37	32	34	—	—	40	23	53	49	35	50
11	37	36	—	26	43	55	43	38	42	44	—	49
12	39	—	41	39	42	47	40	—	44	41	18	49
13	—	32	34	34	—	36	42	33	34	41	18	44
14	38	—	35	29	46	44	38	49	43	—	21	39
15	—	—	35	—	46	40	—	24	26	49	—	47
16	28	37	37	30	42	42	43	50	—	34	36	—
17	34	35	39	30	40	—	40	46	42	38	27	39
18	36	32	—	41	31	37	50	41	45	47	—	43
19	15	—	33	—	38	17	38	—	43	33	16	36
20	15	27	34	—	—	25	—	—	35	37	25	39
21	23	26	35	—	17	25	32	26	41	—	24	35
22	—	—	31	—	25	28	—	36	—	37	38	35
23	17	26	30	41	33	19	36	41	—	30	38	—
24	—	36	42	39	32	—	35	45	55	38	33	—
25	33	25	—	33	44	26	39	52	45	37	—	—
26	30	—	27	38	32	39	45	—	70	33	41	46
27	28	30	17	20	—	41	46	44	80	39	—	47
28	—	32	38	43	42	49	45	32	59	—	—	49
29	—	37	33	—	—	38	—	35	47	26	—	40
30	28		29	51	—	36	44	39	—	24	34	—
31	39		41		62		44	42		24		50
Monthly Average	32	32	34	36	39	38	41	38	46	38	29	44

— No observation.

Stations averaged: Nauen, DFW and DFY; Bordeaux, FYL; Ste. Assise, FTT; Rome, IRB; and Kootwijk, PCG.

NORTH ATLANTIC DAYLIGHT RADIO TRANSMISSION CONDITIONS
1929

Microvolts per Meter

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	—	31	39	50	29	40	36	35	—	39	20	—
2	31	36	35	60	25	—	40	38	—	17	26	16
3	—	—	—	42	42	34	37	32	38	29	—	25
4	35	49	—	35	35	43	—	—	40	27	19	35
5	27	38	42	24	—	35	—	41	48	39	30	41
6	—	21	—	44	38	45	44	—	40	—	40	36
7	39	34	46	—	37	39	—	35	37	44	30	51
8	33	29	42	29	34	—	47	35	—	35	40	24
9	41	38	34	34	35	—	39	32	39	30	37	27
10	43	—	—	38	32	39	36	35	37	34	—	41
11	36	49	38	30	32	27	32	—	43	37	30	39
12	36	40	39	38	—	25	41	43	47	26	15	38
13	—	33	—	51	50	36	36	41	43	—	16	21
14	36	35	—	—	—	40	—	29	39	19	15	26
15	35	34	—	37	—	39	42	39	—	28	14	—
16	52	35	—	29	37	—	39	40	42	28	21	—
17	29	—	—	44	47	35	37	38	26	28	—	55
18	38	38	59	43	43	32	38	—	41	35	24	20
19	38	56	48	38	—	31	70	37	28	38	47	19
20	—	45	67	32	—	30	71	47	37	—	47	36
21	39	52	36	—	41	35	—	43	36	38	41	37
22	33	—	56	23	45	31	35	58	—	—	32	—
23	42	49	43	46	47	—	37	39	29	21	35	34
24	33	—	—	30	36	32	40	40	42	26	—	—
25	32	43	55	—	41	35	33	—	41	42	31	—
26	28	38	45	27	—	39	43	38	40	32	30	48
27	—	52	46	39	40	73	36	35	42	—	38	—
28	29	52	40	—	34	50	—	44	34	22	—	35
29	40		44	34	33	36	61	41	—	27	32	—
30	34		39	25	—	—	41	48	23	12	43	52
31	42		—		32		34	42		24		36
Monthly Average	36	40	45	37	38	37	42	39	38	30	30	34

— No observation.
Stations averaged: Nauen, DFW and DFY; Bordeaux, FYL; Ste. Assise, FTT; Rugby, GBR; Rome, IRB; and Kootwijk, PCG.

NORTH ATLANTIC DAYLIGHT RADIO TRANSMISSION CONDITIONS
1930

Microvolts per Meter

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	—	31	42	42	36	—	37	63	—	81	99	57
2	29	—	—	41	40	65	81	—	47	63	—	56
3	25	42	36	11	41	49	53	58	50	59	22	62
4	35	18	34	38	—	53	—	—	48	42	22	53
5	—	29	28	40	52	52	—	—	44	—	38	50
6	41	41	46	—	37	49	—	—	53	96	35	60
7	34	38	33	42	67	61	59	—	—	82	45	61
8	27	25	27	66	48	—	47	39	53	88	47	45
9	30	—	—	59	58	—	37	—	55	102	—	40
10	—	34	40	57	31	31	42	—	59	56	27	60
11	33	31	31	45	—	40	30	45	54	61	43	57
12	—	45	33	80	50	56	35	44	51	—	41	65
13	25	14	42	—	43	48	—	56	48	47	35	61
14	19	32	43	87	44	54	—	56	—	41	26	68
15	26	43	43	76	40	—	63	63	42	43	25	68
16	53	—	—	39	38	—	57	67	44	46	41	58
17	40	50	39	44	43	—	61	—	46	56	38	58
18	21	48	58	43	—	—	56	73	38	49	39	49
19	—	36	51	55	22	32	52	88	47	—	28	85
20	39	31	38	—	38	30	—	143	45	61	37	48
21	27	29	50	58	—	43	49	46	—	61	19	45
22	21	—	61	45	—	—	50	72	54	68	18	60
23	50	—	—	39	30	—	46	92	60	74	40	46
24	39	32	27	44	50	53	44	—	62	55	34	60
25	48	37	26	—	—	35	49	84	54	55	50	—
26	—	15	30	54	40	32	54	72	45	—	60	55
27	23	29	41	—	46	33	—	80	23	44	49	63
28	—	25	45	27	35	35	38	63	—	98	46	72
29	22		52	45	40	—	50	72	67	55	51	58
30	13		—	44	—	32	58	64	62	98	73	75
31	42		37		—		—	—		48		40
Monthly Average	32	33	40	49	42	44	50	69	50	64	40	58

— No observation.

Stations averaged: Nauen, DFW and DFY; Bordeaux, FYL; Ste. Assise, FTT; Rugby, GBR; Rome, IRB; and Kootwijk, PCG.

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SOME EFFECTS OF TOPOGRAPHY AND GROUND ON SHORT-WAVE RECEPTION*

By

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Summary—*This paper contains some results of an experimental study of the effects which ground and ground irregularities have upon short-wave signal reception. The results illustrate the signal strength advantage to be gained in the selection of suitable ground or topographical conditions and show the influence of antenna types, and vertical angle of signal arrival, upon such an advantage. Although the tests were confined to reception, the conclusions are probably applicable in general to the case of transmission. The agreement between measurement data and theory seems to justify the application of plane wave optical theory to the calculation of vertical plane directivity of antennas. Such an application suggests, according to the data obtained, that signals from South America are normally received at much lower vertical angles than those from England.*

Introduction

The importance of the effects of various types of ground and ground irregularities on the reception of short-wave signals was realized to some extent during the early experimental work on short waves. The magnitude of the effect of surface irregularities first came to our attention when one of the authors[1] a few years ago found a considerable improvement in reception of signals from South America when the receiving antenna was located at the brow of a hill on the short-wave receiving site near Netcong, N. J. At about this same time a test conducted in connection with the ship-to-shore problem had also served to bring out some peculiar effects, particularly those of seaside and marshy surroundings.[2] It was therefore thought advisable to make a more general study of the reception of short-wave signals at several widely different locations. Some of the results of this work are presented in this paper.

Signal Measurement Methods

All the measurements were made with measuring sets of a type which has been in use in the Bell System for several years.[3] An auto-

* Decimal classification: R113. Original manuscript received by the Institute, October 6, 1931.

[1] R. K. Potter.

[2] R. A. Heising, "Effect of shore station location upon signals," Proc. I.R.E. 20, 77–87; January, 1932.

[3] H. T. Friis and E. Bruce, "A radio field strength measuring system for frequencies up to forty megacycles," Proc. I.R.E., August, 1926.

matic recording attachment made up of a modified Leeds and Northrup recorder was used in several cases. This recorder, a photograph of which is shown in Fig. 1, gives a continuous record of the voltage delivered by the antenna, integrating this voltage over a period of ten

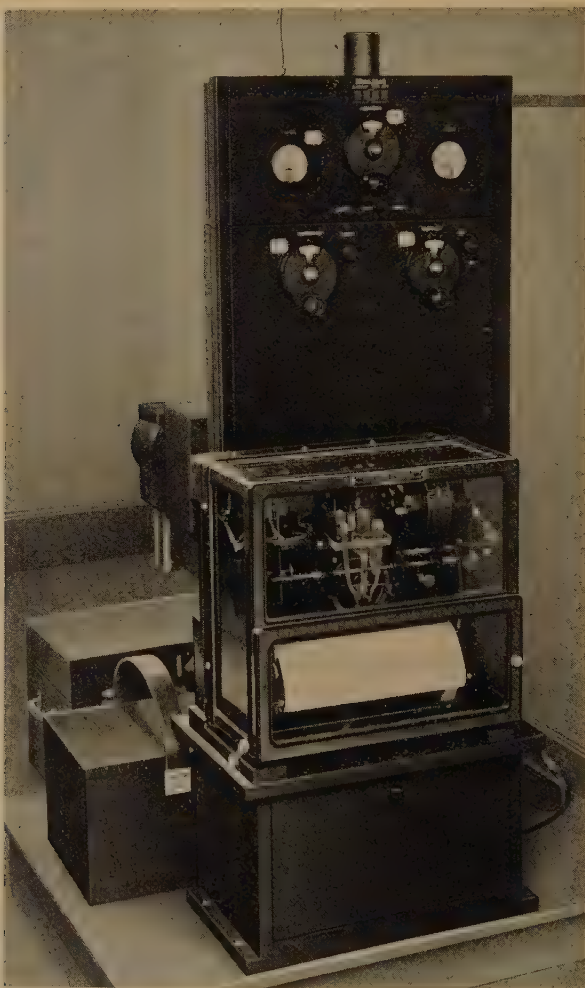
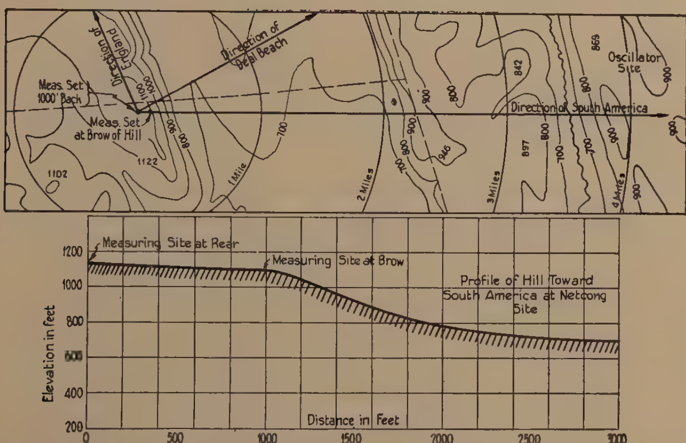


Fig. 1—Field strength measuring set with automatic recorder.

seconds, by means of a condenser-resistance circuit. The recorder mechanism tends to maintain the output of the receiver at a constant level by changing the receiver attenuator setting at the end of each ten seconds.

The antennas used in these tests were, in general, not elevated more than a half wavelength above ground. They consisted of short vertical rods or half-wave wires. With the constants of the antenna known the received field may be expressed in microvolts per meter.[4] In the tests described, however, the interest is confined to the relative signal output of separate receiving systems, the distance between comparison sites being such that it is reasonable to assume that the strength of incident signal arriving from a source several thousand miles away was on the average the same at the comparison points. The procedure was, therefore, to have two sets of apparatus as nearly similar as possible, and to operate them simultaneously at the two sites which were under



'ig. 2—Section of contour map showing situation of Netcong measuring sites in relation to hill brow and direction of signal arrival. Below, approximate profile of slope toward South America.

omparison. Careful checks were made before and after every test to ssure that this apparatus was functioning properly. These checks were nade by setting up the measuring sets with their associated antennas bout three wavelengths apart and making simultaneous measureents of the same signal. The check measurements usually agreed rithin one decibel[5] (1.1 times).

[4] Due to ground reflections, field strength measurements do not, in general, fer to the incident field alone but always the combined effect of the direct and flected waves. For this reason the interpretation of measurements in microolts per meter at short wavelengths loses much of its significance. When an exnded antenna such as a vertical half wave is used the matter is still further mplicated on account of the variation of field over the antenna length.

[5] The voltage ratio expressed in decibels is 20 $\log_{10}$ (output voltage ratio).

The Effect of Topography

During the summer of 1929 prior to the establishment of the radiotelephone circuit to South America a large number of field strength measurements were made on South American short-wave stations at the short-wave receiving terminal located near Netcong, N. J. Simultaneous measurements were made on different parts of the site with

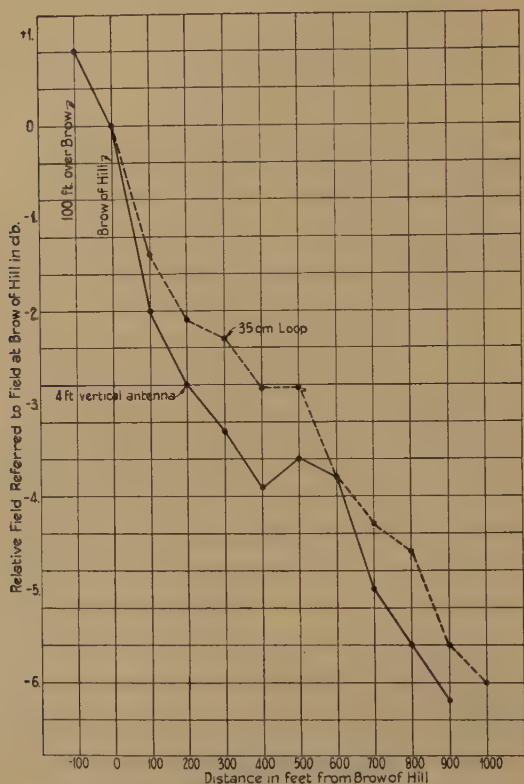


Fig. 3—Decrease in signal received from oscillator four miles away with distance from hill brow. Measurements with vertical antenna and loop on 14.75 mc.

the object of determining the advantage to be derived from a particular location of receiving antennas.

The Netcong site is on the flat top of a ridge three or four hundred feet above the surrounding valleys. In the direction of South America the hill breaks rather abruptly from a gradual slope to a grade of between twenty and thirty degrees. In the upper part of Fig. 2 is shown

the site in contour as taken from the U.S.G.S. map.[6] At the bottom of Fig. 2 is shown a profile of the hill in the direction of South America.

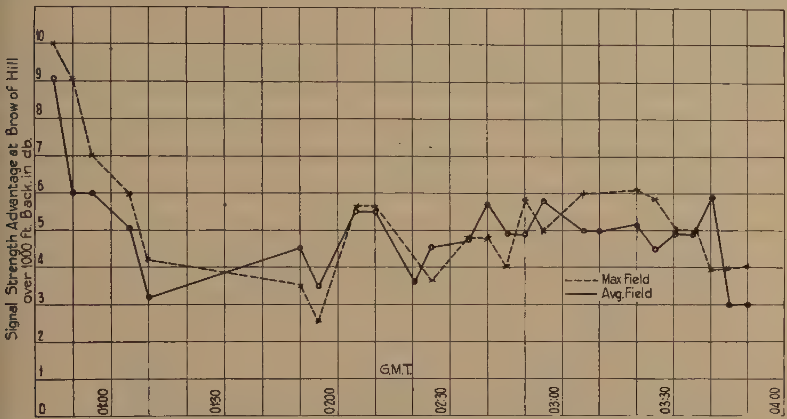


Fig. 4—Diurnal trend of signal strength advantage at brow of hill toward South America over reception 1000 feet back for LSD (Buenos Aires) on 8.83 mc.

The early measurements indicated that the fields near the brow of the hill were on the average very appreciably higher than those about

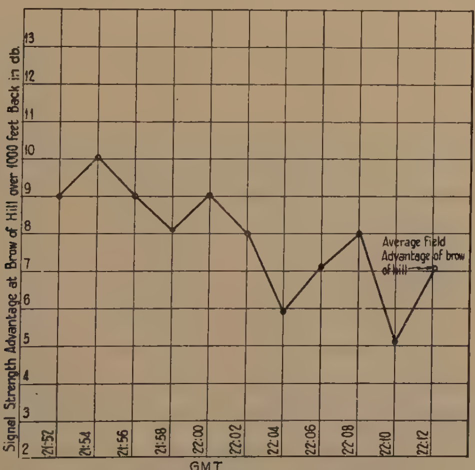


Fig. 5—Short period trend of signal strength advantage at brow of hill toward South America over reception 1000 feet back for PJZ (Curaçao) on 12.195-mc vertical antennas.

a thousand feet back from this point. To test the effect more accurately than was possible without extended observations of the fading signals

[6] U. S. Geological Survey topographical map, New Jersey—Lake Hopatcong quadrangle.

from distant stations an oscillator was set up on another high hill, about four miles away, in the direction of South America. The oscillator location was clearly visible from the ground level at all of the measurement points, although the angle of reception was slightly below the horizontal. The relative fields (at 14.75 megacycles) as measured on a four-foot vertical rod and a thirty-five centimeter loop are shown in Fig. 3. Though the ground over the edge of the hill was too rough to set up a measuring set conveniently, it appears from one measurement that the fields continued to increase below the brow. Subsequent

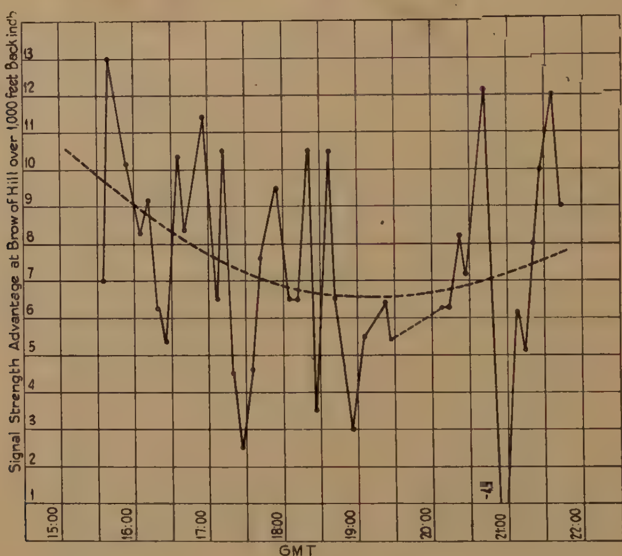


Fig. 6—Diurnal trend of signal strength advantage at brow of hill toward South America over reception 1000 feet back for LSE (Buenos Aires) on 20.54-mc vertical antennas.

check measurements indicated that the divergence of the curves for the loop and vertical antenna in Fig. 3 was real.

With one measuring set at the brow of the hill toward South America and another 1000 feet to the rear, field strength measurements were made manually of signals received from the direction of South America. Some representative results are shown in Figs. 4, 5, and 6. The field strength advantage at the brow of the hill is expressed in decibels. The average increase in field according to these earlier measurements amounted to something over 6 db (2.0 times) and on occasions was considerably greater. The advantage of the hill brow site was always highest toward the beginning and end of the period during which the frequency of the signal measured would normally be used. This is il-

lustrated by the incomplete diurnal characteristics of Figs. 4 and 6. That these times probably correspond to the times when the vertical angle of reception is lowest, will be evident later in the discussion.

In Fig. 7 are some 18.34-megacycle measurements of transmission from WND at Deal Beach, N. J., which, as shown by Fig. 2, lies in a

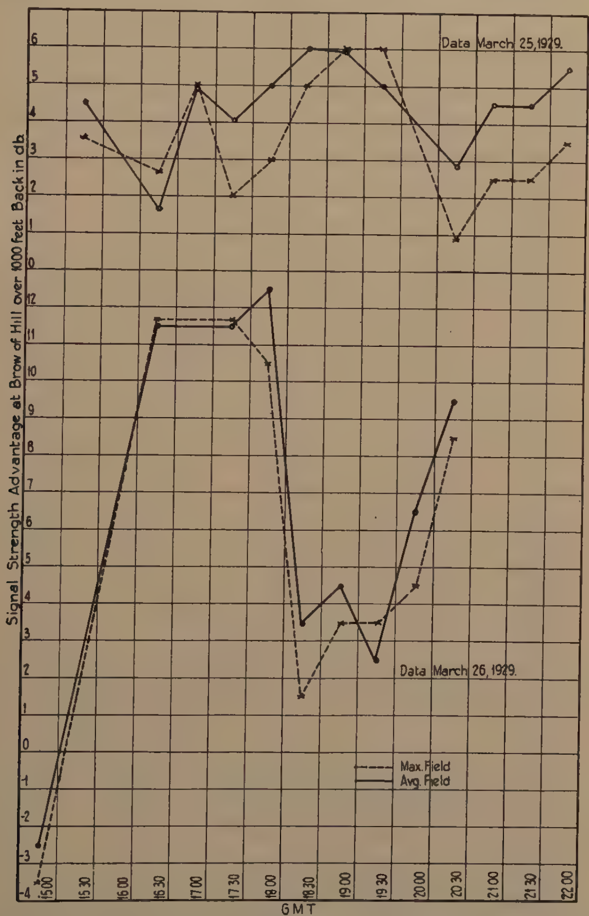


Fig. 7—Diurnal variation in signal strength advantage at brow of hill over reception 1000 feet back for WND on 18.34 mc (60 miles away in direction of slope).

direction nearly perpendicular to the brow of the hill about sixty miles away. Although there was a substantial advantage at the brow of the hill the diurnal variation from day to day for this short range case seemed to be quite erratic. This may have been in some way related to the fact that the receiving site at Netcong is some eighty degrees off

the main lobe of the directive pattern for the WND array facing England, or possibly to a change in the proportion of signal contributed by a high angle sky wave.

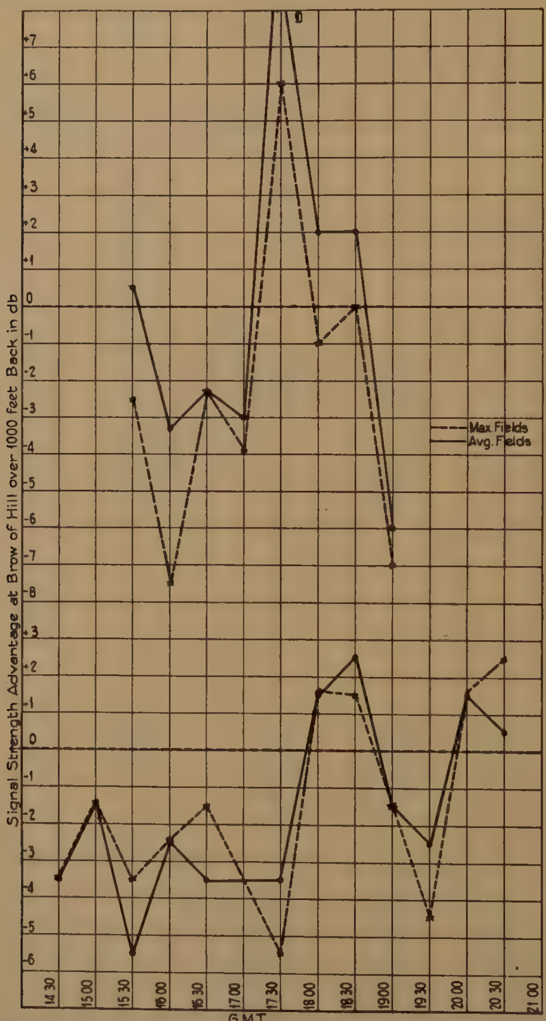
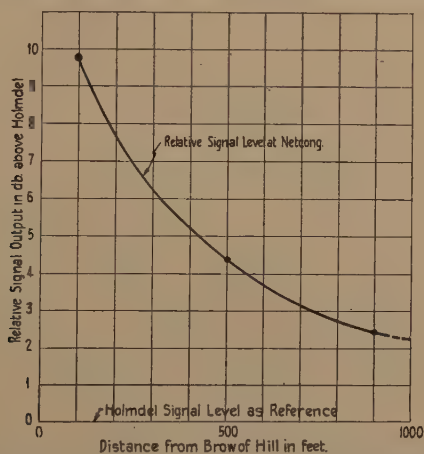


Fig. 8—Diurnal variation in signal strength advantage at hill brow toward South America over reception 1000 feet back for GBS (England) on 18.31-mc vertical antennas.

In Fig. 8 is illustrated the advantage of reception at the brow of the hill for signals from England. As shown in Fig. 2 this direction is approximately at right angles to the direction of the slope. Although, over short periods of time, there may be a considerable difference in meas-

ring set output for signals from England at the two points, there is ttle or no difference when the measurements are averaged for several ours. While the curves of Fig. 8 are only for a particular station and ·equency, they are, in general, representative of meaurements that ·ere made on other stations in this same direction and on other fre-uencies.

During the latter part of 1930, a further test of the reception ad-antage near the brow of the hill described above was made with field :rength measuring sets equipped with the type of automatic field ecorder previously described. Using two of these automatic field :rength recorders with half-wave vertical antennas, relative fields from :ation LSN (Buenos Aires) on 21.020 megacycles were measured



g. 9—Variation of signal output from vertical half-wave antenna with distance from hill brow toward South America at Netcong referred to Holmdel sig-nal—LSN on 21.02 mc.

multaneously at the Bell Telephone Laboratories' experimental site ear Holmdel, N. J., and at one of three points at different distances om the hill brow on the Netcong site. (The ground in the vicinity of e Holmdel site is comparatively flat for some distance in the direction reception.) On successive days measurements were made at the Net-ng site near the brow of the hill, and approximately 500 and 1000 et back. In Fig. 9 are shown, expressed in decibels, the average rela-ve levels of fields for the three Netcong points obtained by compari-n with simultaneous measurements at Holmdel. Incidentally the ope of the curve in Fig. 9 may be some indication of the distance to hich the constants of the ground surrounding a 21-megacycle receiv-g antenna may have an appreciable effect upon the received signal tensity.

During January, 1931, further tests were made to ascertain whether this hill brow advantage was confined to reception of the vertical component of the electric field. Identical horizontal doublets, each three-quarters of a wavelength long and one-half wavelength above the ground were erected at the brow of the hill and about 1100 feet in the rear. In both cases a two-wire lead-in was brought down to a balanced

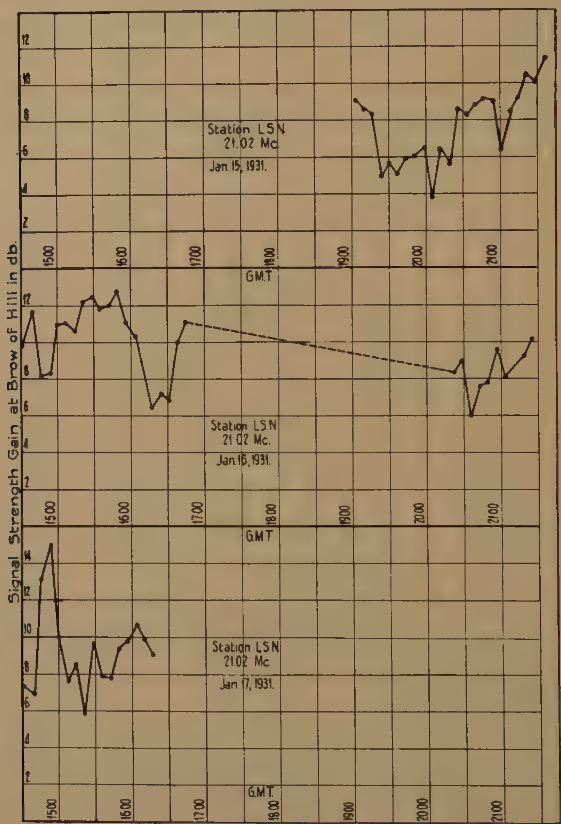


Fig. 10—Diurnal variation of signal strength advantage at brow of hill toward South America over reception 1000 feet back for 21-mc signal from LSN (Buenos Aires) received on horizontal doublets.

antenna circuit forming the input to a measuring set. Measurements of relative field were made manually at the two points on station LSN transmitting 21.020 megacycles. The diurnal change in gain of signal strength at the brow of the hill for the period of the tests is shown in Fig. 10. The average gain based upon all the horizontal doublet measurements made at this time amounted to 8.8 decibels (2.75 times

vhich was somewhat higher than that obtained on the average for re-eption on vertical antennas. The average gain in 21-megacycle signal ıt the brow of the hill over that received 1100 feet back was, for all the arlier 21-megacycle measurements made on vertical antennas, between and 8 decibels.

The sense of the difference between the hill brow gains for the hori-ontal and vertical antenna measurements corresponds to that which night be predicted by theory according to Figs. 13 (A) and (C). That s, for the lower angles of reception the rate of change of output with hange in the vertical angle of signal arrival is greater for the horizontal han for the vertical antenna. The magnitude of the difference obtained lso agrees reasonably well with what might be predicted by theory if is assumed that the signals are received at a vertical angle of some

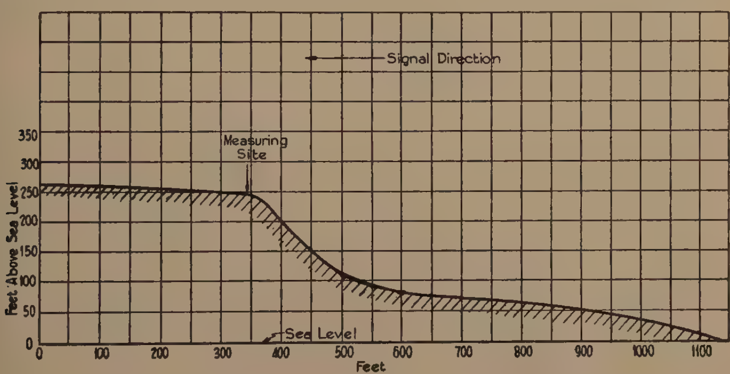


Fig. 11—Approximate profile of Atlantic Highlands site.

ve degrees or less, and the flat ground characteristics are simply tilted ownward to provide optimum reception when the antennas are placed t the hill brow.

Some attempts that have been made to obtain a hill brow advantage ır reception from England have not been as fruitful as for the case of ception from South America. During the summer of 1927, several ıys' comparsion measurements of signals from England were made at ne brow of a cliff facing England in the Atlantic Highlands, and at the xperimental receiving station of the Bell Laboratories, then located Cliffwood, N. J. A profile of the Atlantic Highland site is shown in ig. 11. The measurements made at this time showed but a small ad-ıntage in reception at the brow. The probable reason for the decrease hill brow advantage in this case will be discussed later.

Fig. 12 consists of two superimposed automatic field strength re-ırder records of 18-megacycle signals from England which were taken

Fig. 12—Field strength records of GBS (England) on 18.310 mc taken at Holmdel and hill at Atlantic Highlands, New Jersey, using vertical antennas. Data, November 21, 1930.

simultaneously at the Atlantic Highlands and Holmdel sites. Vertical half-wave antennas were used. It will be noticed that although the average gain in signal at the cliff is generally small there is some improvement during the earlier hours. This improvement is similar to that mentioned in connection with the measurements at the Netcong site on reception from South America. Possibly in this case also it has something to do with a low angle of arrival in the early part of the useful signal period.

A few comparative measurements of signals from England have been made on a gradual slope toward England near the Netcong site. The most pronounced slope available was in this instance much more gradual than that toward South America. The signal strength advantage at the edge of this slope as compared to a point on comparatively flat ground was small during the period of several hours over the middle of the day when these measurements were made.[7]

Unless there is some topographic peculiarity for the Netcong site in the direction of South America that is not duplicated in the conditions at Atlantic Highlands in the direction of England, it would appear that there is a characteristic difference in the signals from England and South America. Probably the difference is one of vertical angle of signal arrival. It is known that, on the average, signals from England are received at fairly high angles.[8] The effects so far described can be accounted for by assuming that signals from South America are received at a relatively low angle.[9]

In Fig. 13 diagrams (A) and (C) show calculated vertical plane directional characteristics for vertical and horizontal antennas over ground which was flat and which had electrical characteristics similar to those for the Netcong site. The characteristics are calculated from plane wave optical theory by means of the reflection constant, and phase angle curves as given by Pedersen.[10] (These, and the characteristics discussed later, are all based upon the assumption of equal incident fields.) Diagrams (B) and (D) of this same figure illustrate the way in which the vertical pattern for these two antennas, in their relation to a low angle wave

[7] *Note:* Some recent measurements of 14.44-mc signals from England on this same slope have shown an average hill brow gain of about 7 db during the early part of the normal useful period. Within a few hours the advantage decreases to 3 or 4 db, and there are indications of an increase again toward the end of the period. Possibly these values are subject to a seasonal variation.

[8] H. T. Friis, "Oscillographic observations on the direction of propagation and fading of short waves," Proc. I.R.E., **16**, 658, 1928.

[9] *Note:* Arrangements are at present being made to determine the vertical direction of arrival of South American short-wave signals at the Holmdel experimental site.

[10] P. O. Pedersen, "The Propagation of Radio Waves," Copenhagen, 1927, p. 132–135.

(as indicated by the arrows), is modified by placing them on a sloping ground. For low angle waves it is evident that sloping ground would

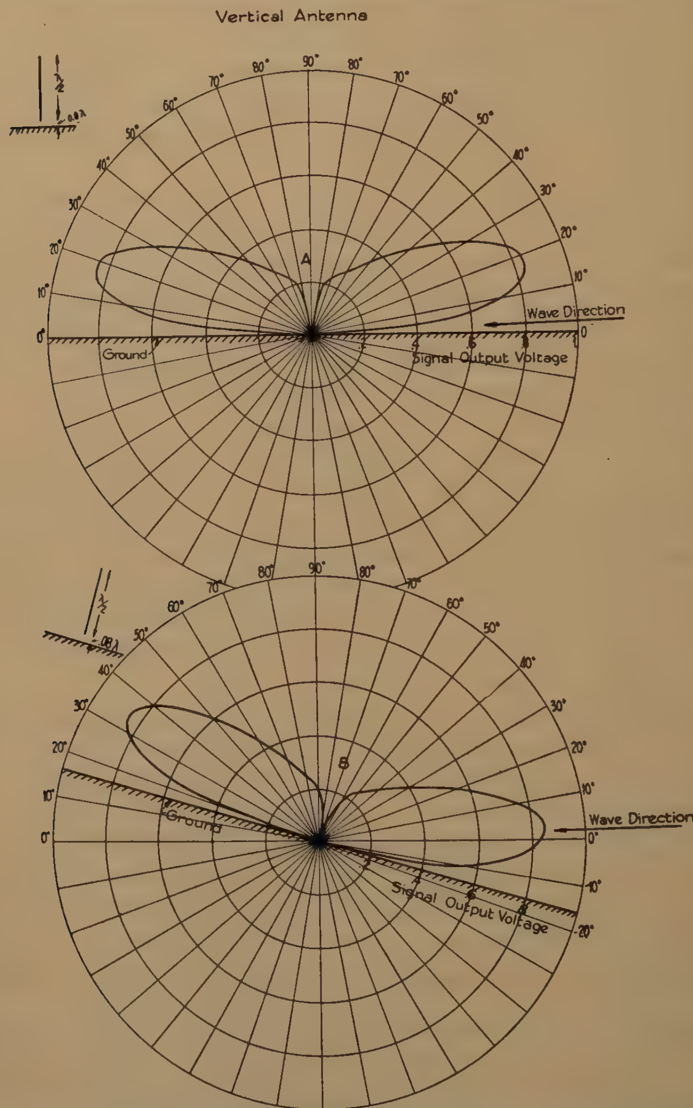
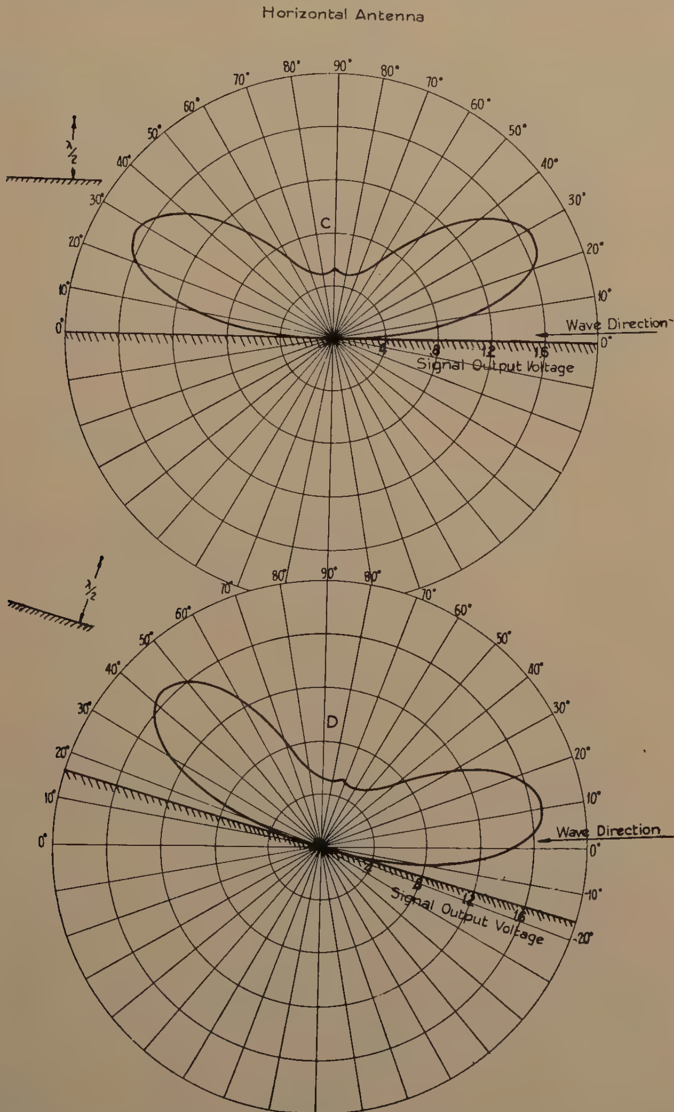


Fig. 13 A and B—(A) Calculated vertical directional characteristic for half-wave vertical over "Netcong" ground. (B) Effect of sloping ground in case of low angle reception on vertical antennas. Note: "Netcong" ground assumed $\sigma = 3.3 \times 10^{-14}$ $\epsilon = 7$.

provide the most advantageous receiving site with either vertical or horizontal antennas. For signals arriving over a wide range of vertical

angles, such as is the case with signals from England, little gain would normally be expected at the brow of the hill. The conditions at Net-



ig. 13 C and D—(C) Calculated vertical directional characteristic for horizontal doublet elevated half a wavelength above "Netcong" ground. (D) Effect of sloping ground in case of low angle reception on horizontal doublet. Note:—"Netcong" ground assumed $\sigma=3.3\times10^{-14}\epsilon=7$.

ong are not as simple as those shown in Fig. 13, (B) and (D). In the ctual case the slope is constant for only a few hundred feet and the

exact calculation of the directive characteristic under such conditions becomes difficult.

Effect of Ground Constants

An effect similar to that observed in the hill brow studies has been noticed in the reception of short-wave signals from England and South America with marshy ground or salt water immediately adjacent in the direction of reception. Many hours of simultaneous automatically recorded measurements of 18-megacycle signals from England on the Holmdel site and on marshy ground along the shore of Barnegat Bay, N. J., using vertical antennas at both points, showed no noticeable average difference in received signal strength.

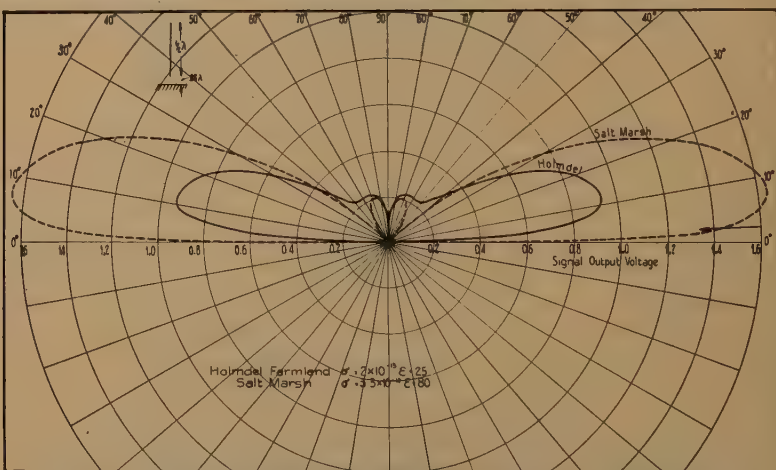


Fig. 14—Vertical plane directional characteristic of a half-wave vertical antenna for two types of ground.

Vertical antenna measurements (automatically recorded) of 21-megacycle signals from South America on marshy ground along the shore of the South Shrewsbury River in Rumson, N. J., indicated an average improvement of over 8 decibels (2.5 times) when compared to signals received at the Holmdel site. This, again, may be accounted for on the assumption that the signals from South America arrive at a comparatively low angle approaching grazing incidence. Theoretical considerations indicate that the vertical antenna on marshy, highly conductive ground would be more receptive to signals arriving at low angles than a similar antenna on dry ground such as that in the vicinity of the Holmdel site.

In Figs. 14 and 15 are shown the calculated vertical plane directional characteristics plotted, respectively, in polar and rectangular co-

ördinates for a vertical half-wave antenna over two types of ground, one corresponding to marshy land as encountered at Rumson, the other to the Holmdel soil conditions. By way of example consider a signal arriving at an angle of 3 degrees above the horizon as is indicated by the arrow in Figs. 14 and 15. The signal should, according to the curves, give 9 db (2.8 times) higher antenna output at the marshy site. Since

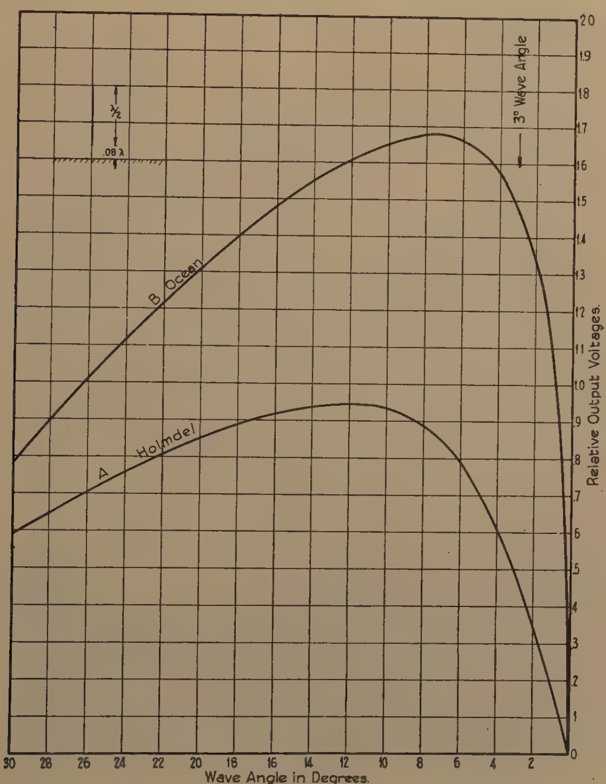


Fig. 15—Vertical plane directional characteristics of a half-wave vertical antenna for two types of ground:
A—Holmdel farmland ($\sigma = 2 \times 10^{-13} \epsilon = 25$).
B—Salt marsh ($\sigma = 3.3 \times 10^{-11} \epsilon = 80$).

this gain corresponds approximately to the measured value, it appears that the average angle of reception of the South American signals is on the order of a few degrees above the horizontal.

In Fig. 16 are shown the vertical plane directional characteristics for both horizontal and vertical doublets elevated half a wavelength above ground. The ground conditions assumed are the same that were assumed for the calculation of the curves of Figs. 14 and 15. These char-

acteristics show that a change in ground conditions should have relatively little effect upon the reception of low angle signals with a horizontal antenna. It would, therefore, be expected that the advantage in this case of a difference in soil conditions would be confined to the reception of the vertical component of the electric field. Automatic signal strength measurements carried out during July, 1931, are in agreement

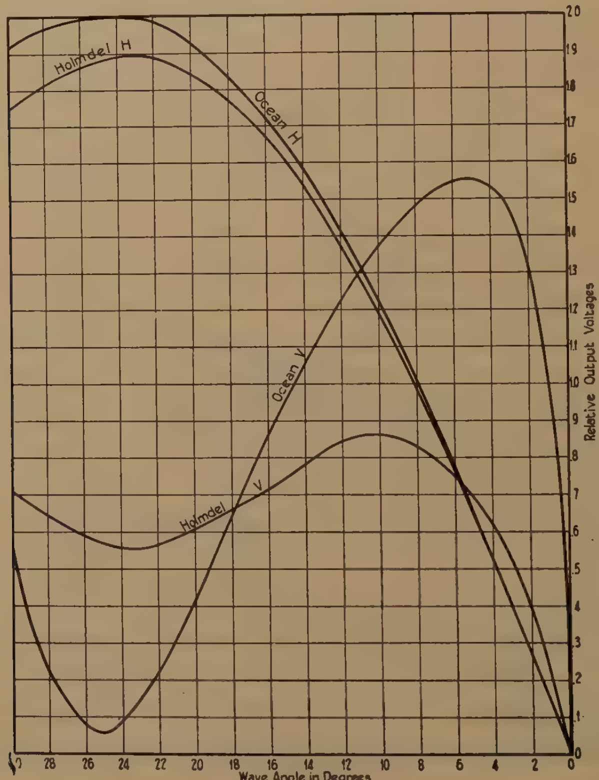


Fig. 16—Vertical plane directional characteristics of horizontal and vertical doublets elevated 0.6λ for two types of ground:
A—Holmdel site (farmland) $\sigma=2\times10^{-13}\epsilon=25$.
B—Ocean site (salt marsh) $\sigma=3.3\times10^{-11}\epsilon=80$.

with this conclusion. The measurements were made at the same sites (Holmdel and Rumson, N. J.) as before, and on signals from LSN (21.020 megacycles). Loaded Hertzian doublets, self-resonant at 21 megacycles and capable of quick adjustment from horizontal to vertical position, were used for antennas.

Fig. 17 shows a photograph of the adjustable doublet and the truck containing the measuring set and recorder. The center of the antenna

was a little over a half wavelength (27 feet) above ground. A twisted pair (No. 18 lamp cord) transmission line was tapped across the central two turns of the eleven-turn loading coil. This transmission line was terminated in a balanced circuit which was inductively coupled to an unbalanced circuit. A photograph of this terminating arrangement is shown in Fig. 18. From the unbalanced output circuit a short length of pipe transmission line carried the signal to the antenna circuit of the

Fig. 17—Adjustable receiving doublet and truck containing field strength recorder.

measuring set. When the doublet was horizontal this system gave a very good discrimination (more than 25 db) against vertically polarized waves. With the doublet in a vertical position a similar discrimination was obtained against horizontally polarized waves.

Measurements were made simultaneously at Rumson and Holmdel of 21-megacycle signals from LSN on three days covering about 15 hours of recording. The records showed that the average signal outputs using the doublets in the horizontal position at the two sites were prac-

tically the same. The variations during any day were seldom greater than plus or minus 2.5 db (1.3 times).

On two of the three days measurements were made with the doublets in alternately vertical and horizontal positions for successive half-hour periods. With the doublets in the vertical position the average for this two-day period showed the signal output at the marshy site near Rumson to be 13 db (4.5 times) higher than that at Holmdel. Thus, when the site is marshy or wet, there may be a considerable signal output advantage in using an antenna of the vertical type. The records obtained at the two sites during one of these days are shown

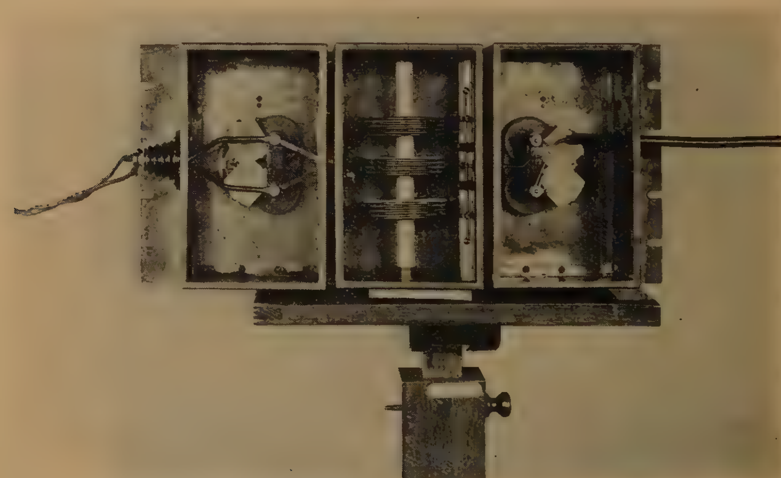


Fig. 18—Terminating circuit at end of transmission line from adjustable doublet.

superimposed in Fig. 19. The increase in signal output at the Rumson site accompanying a change in the doublet positions from horizontal to vertical is quite apparent.

The evident continuity of the record for the Holmdel site, despite the change in position of the receiving doublet, shows clearly that there is little to choose between horizontal and vertical antenna types over dry soil typical of that vicinity when the angle of a signal arrival is small. A consideration of these results in connection with the Holmdel V and H curves of Fig. 16 indicates that the field strengths of the horizontal and vertical components of the incident wave are equal.

The data discussed thus far, in connection with the effect of ground constants on reception, have been concerned only with the 21-megacycle signals from South America which are presumed to arrive at low

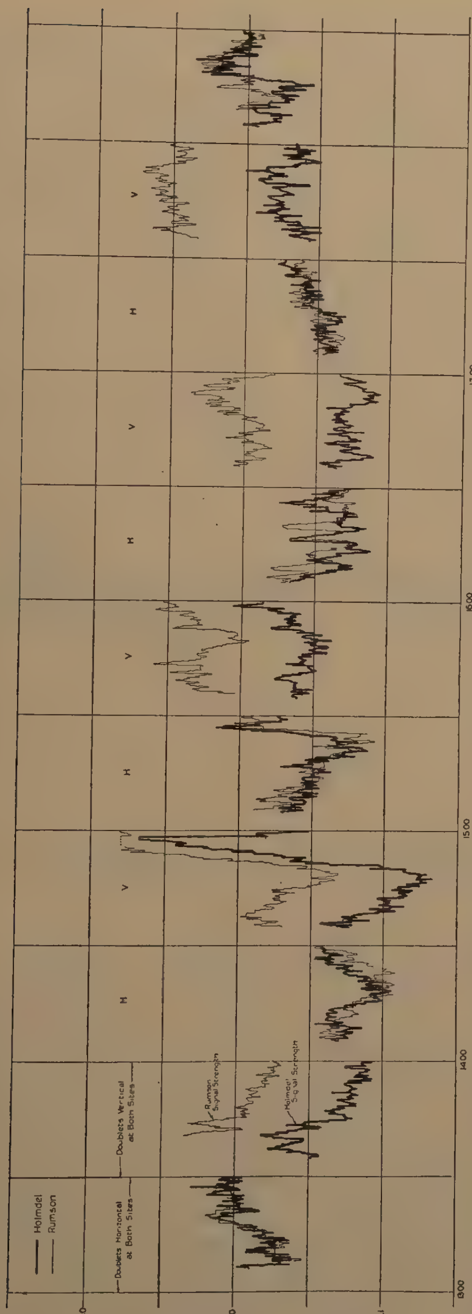


Fig. 19—Field strength records of 21 mc signals from LSN (Buenos Aires) taken on flat farmland at Holmdel, New Jersey, and salt marsh at Rumson, New Jersey. *H* indicates horizontal doublet. *V* indicates vertical doublet. Data, July 15, 1931.

angles. In the Barnegat Bay-Holmdel comparison measurements, mentioned earlier, there is some interesting evidence concerning the vertical direction of 18-megacycle signal arrival from England. These measurements were made on vertical antennas. Although the average advantage in reception at the marshy site near Barnegat Bay was small there were occasional periods of from 5 to 30 minutes during which large differences appeared. Within the period of the test these differences frequently ran around 8 to 10 db, and once reached 15 db.

At a later date (July 21, 1931), records were made with a vertical antenna of 18-megacycle signals received from England at Holmdel and on a salt marsh near Port Monmouth, N. J. The salt marsh site was similar to that formerly used on Barnegat Bay near Ocean Gate.

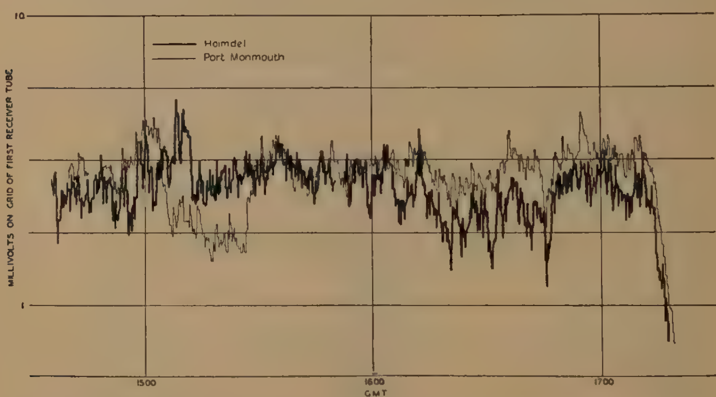


Fig. 20—Field strength records of GBU (England) taken on flat farmland a Holmdel, New Jersey, and salt marsh at Port Monmouth, New Jersey, usin vertical antennas. Data July 21, 1931.

The record is shown in Fig. 20. It illustrates the way in which the rela tive signal output at the two sites changed during some 20 minute (1505 to 1525 G.M.T.). The variations are similar to those which wer recorded during the earlier measurements. One evident explanation o this interchange of advantage is that the difference in signal strengt at the two points separated by several miles may have been produce by slow wave interference fading for which the space separation of in terference minima might be large. Another possible explanation is tha the vertical angle of arrival of the signals was always the same at th two sites but varying slowly between 0 and 50 degrees. Referring to th two characteristics in Fig. 14 it is evident that a high angle of incidenc would favor the Holmdel site while a low angle would favor the site a Barnegat Bay.

Conclusions

The principal merit in this discussion of certain special cases of ound and ground surface effects, is perhaps that it will serve to em- asize the importance of these factors in dealing with transmission, ception, and measurement problems. Antenna and ground are in- mately related in the determination of vertical plane directivity. In any cases it may be economically impractical or even impossible to tain the most desirable vertical directivity in an antenna system ithout some special considerations in the selection of a site as well as antenna.

Acknowledgment

Measurements of the kind which form the basis of this discussion ecessarily require the coördinated effort of many individuals, and the ork of those taking part in this study has been appreciated. In this nnection, acknowledgement is due Mr. W. W. Mutch who had charge the recording and Mr. A. C. Peterson who was responsible for most the manual measurement work at Netcong.

We are particularly indebted to Mr. C. B. Feldman who contributed e theoretical directional characteristics and assisted otherwise in the terpretation of results.

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RESISTANCE-CAPACITANCE COUPLED AMPLIFIER IN TELEVISION

A Transient Solution for the Performance of the Resistance Capacitance Coupled Amplifier on Characteristic Television Signals*

By

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(The Boston Post, Boston, Massachusetts)

Summary—*The resistance-capacitance coupled amplifier as employed in tele vision systems lends itself fairly readily to the complete, as against the steady-state solution of its performance. This is due to the fact that the television signal can b resolved into a simple and definite time function. The following paper presents c method of obtaining the transient or complete solution of the amplifier performanc under the excitation of typical television signal impulses.*

It is seldom that communication circuits lend themselves agreeabl to transient solutions. It is usually much easier and more satisfac tory to consider only the steady-state solution for applied voltage which vary sinusoidally with time.

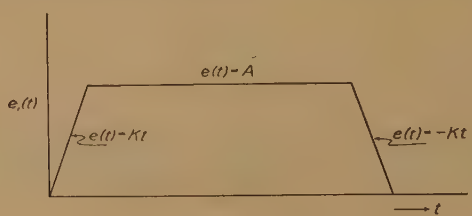

Fig. 1

In the case of the multistage, resistance-capacitance coupled am plifier which is commonly used in television circuits, a complete solu tion for certain types of impressed voltage can be obtained withou great difficulty. The form of the input voltage is a function of the ligh reflected from a scanning spot. Assuming a square spot, it is easy to pre dict the form of the voltage impressed upon the amplifier as the spo traverses a region of constant contrast and with sharp boundaries. Th problem is to determine the form of the output voltage.

This elementary type of impressed voltage is illustrated in Fig. 1 It is divided into three regions, one of growth, one in which it is con

* Decimal classification: R363. Original manuscript received by the Insti tute, September 25, 1931.

stant and a third of decay. Such a variation in impressed voltage can be synthesized from the single impressed voltage of the form

$$e(t) = \pm Kt$$

applied at different times. The problem, therefore, boils down to one of finding the amplifier response to an impressed voltage of the form

$$e(t) = \pm Kt.$$

The operational calculus provides a convenient and rapid means for obtaining this solution. The method may be illustrated by means of a simple, equivalent network. The amplifier circuit may be represented as a simple ladder structure of resistance and capacitance elements as shown in Fig. 2. The successive sections are normally coupled through a three-element vacuum tube. Hence, the current flowing in one loop

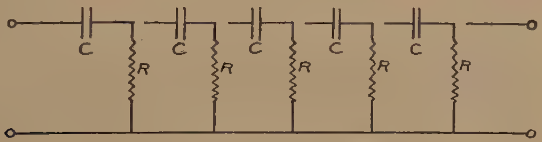

Fig. 2

through the resistance introduces no voltage drop nor rise in the preceding loop. The resistances are not mutual parameters in the usual sense.

Referring to Fig. 2, the voltage $e_1(t)$ applied to the input terminals of the network produces the current in the first loop

$$i_1(t) = \frac{1}{z(p)} e_1(t) \text{ where } z(p) = R + \frac{1}{cp} \cdot$$

The voltage appearing across the resistance in the first loop becomes

$$e_2(t) = Ri_1(t).$$

This is also the form of the voltage impressed upon the second loop

$$i_2(t) = \frac{1}{z(p)} e_2(t) = \frac{R}{z(p)} i_1(t) = \frac{R}{[z(p)]^2} e_1(t)$$

$$i_3(t) = \frac{R^2}{[z(p)]^3} e_1(t)$$

$$\cdots\cdots$$

$$i_n(t) = \frac{R^{n-1}}{[z(p)]^n} e_1(t).$$

The factor R^{n-1} affects only the magnitide and not the form of the resultant current and can be reduced to unity for our purpose.

Substituting the value of $z(p)$,

$$i_n(t) = \left(\frac{1}{R + \dfrac{1}{cp}}\right)^n e_1(t)$$

$$= \frac{1}{R}\left(\frac{p}{p+b}\right)^n e_1(t) \quad \text{where } b = \frac{1}{RC}\cdot$$

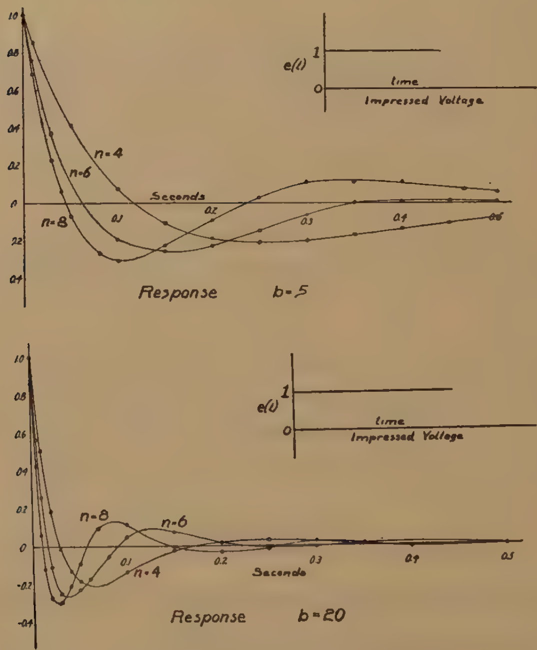

Fig. 3

Once more reducing the constant term to unity

$$i_n(t) = \left(\frac{p}{p+b}\right)^n e_1(t).$$

This is a general operational expression for a network of n loops and time constant, b. This expression may be solved for the special case where the applied voltage $e_1(t)$ becomes unit applied voltage, 1.

$$A_n(t) = \left(\frac{p}{p+b}\right)^n 1.$$

This is identical in form with the transfer indicial admittance of the network for unit applied voltage at the input. Unit applied voltage has the form illustrated in Fig. 3 and is the form approached as the scanning spot of the television system becomes smaller and smaller.

The operator $(p/p+b)^n$ is descriptive of the network and it can be shown that the same operator describes the actual resistance-capacitance coupled amplifier circuit and that only the value of b is affected by the tube parameters.

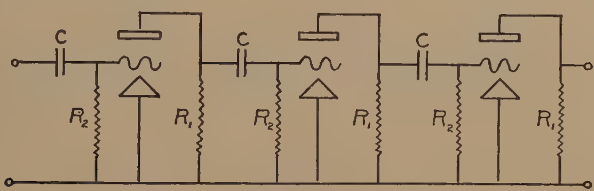

Fig. 4

Following the procedure above, the tube parameters will be included as shown in Fig. 4.

In general,

$$di_p = \frac{\mu}{r_p + z(p)} de_g.$$

For the circuit in Fig. 4,

$$z(p) = \frac{1}{\dfrac{1}{R_1} + \dfrac{1}{R_2 + \dfrac{1}{pC}}} = \frac{R_1R_2Cp + R_1}{pC(R_1 + R_2) + 1}$$

$$i_1(t) = \frac{\mu}{r_p + z(p)} e_1(t).$$

The voltage impressed upon the grid of the second tube becomes

$$e_2(t) = R_2\left[\frac{R_1}{R_1 + R_2 + \dfrac{1}{pC}}\right] i_1(t)$$

$$= R_2\left[\frac{R_1}{R_1 + R_2 + \dfrac{1}{pC}}\right]\left[\frac{\mu}{r_p + (zp)}\right] e_i(t)$$

and,

$$i_2(t) = \frac{\mu}{r_p + z(p)} e_2(t)$$

$$= R_2 \left[\frac{R_1}{R_1 + R_2 + \dfrac{1}{pC}} \right] \left[\frac{\mu}{r_p + z(p)} \right]^2 e_1(t).$$

Similarly,

$$e_3(t) = R_2{}^2 \left[\frac{R_1}{R_1 + R_2 + \dfrac{1}{pC}} \right]^2 \left[\frac{\mu}{r_p + z(p)} \right]^2 e_1(t).$$

In general,

$$i_n(t) = R_2{}^{n-1} \left[\frac{R_1}{R_1 + R_2 + \dfrac{1}{pC}} \right]^{n-1} \left[\frac{\mu}{r_p + z(p)} \right]^n e_1(t)$$

or,

$$e_{n+1}(t) = R_2{}^n \left(\frac{R_1}{R_1 + R_2 + \dfrac{1}{pC}} \right)^n \left(\frac{\mu}{r_p + z(p)} \right)^n e_1(t).$$

Substituting the value of $z(p)$ and simplifying,

$$e_{n+1}(t) = \left(\frac{R_1 R_2 \mu}{R_1 r_p + R_2 r_p + R_1 R_2} \right)^n \left(\frac{p}{p + b} \right)^n e_1(t)$$

where,

$$b = \frac{R_1 + r_p}{C(R_1 r_p + R_2 r_p + R_1 R_2)}.$$

The constant term in the expression for $e_{n+1}(t)$ may be reduced to unity and so far as the form of the output circuit current is concerned, the amplifier has identically the same operator as obtained for the simple ladder network.

Hence,

$$A_n(t) = \left(\frac{p}{p + b} \right)^n 1.$$

Solution of such an operational expression as an explicit time function is greatly facilitated by first applying the Heaviside shifting formula

$$\frac{1}{z(p)}1 = e^{-bt}\frac{p}{p-b}\cdot\frac{1}{z(p-b)}1$$

hich yields

$$A_n(t) = e^{-bt}\left(\frac{p}{p-b}\right)\left(\frac{p-b}{p}\right)^n 1$$

$$= e^{-bt}\left(\frac{p-b}{p}\right)^{n-1} 1.$$

his expression can now be expanded and each term allowed to operate dependently upon the unit time function. For example, let $n=3$. hen,

$$i_3(t) = e^{-bt}\left(\frac{p-b}{p}\right)^2 1$$

$$= e^{-bt}\left(1 - \frac{2b}{p} + \frac{b^2}{p^2}\right)1$$

$$= e^{-bt}\left(1 - 2bt + \frac{b^2t^2}{2}\right).$$

ıus, we have for $t>0$ a complete solution for the amplifier response terms of the number of stages and the time constant, b, for an im- essed voltage of the form of the unit voltage suddenly impressed at ne zero. This would be sufficient were we interested in the amplifier sponse to impulses of rectangular shape.

Fig. 3 shows the form of the transfer indicial admittance of the am- ifier for different values of n and of b.

Our problem is to determine the amplifier response to an applied ltage of the form

$$e_1(t) = Kt.$$

For this purpose, one form of the superposition theorem is ad- rably suited. It states

$$i_n(t) = e_1(0)A_n(t) + \int_0^t A_n(t-\lambda)e_1'(\lambda)d\lambda$$

ıce,

$$e_1(0) = 0$$

d,

$$e_1'(\lambda) = K$$

this form reduces to

$$i_n(t) = K \int_0^t A_n(t - \lambda) d\lambda.$$

The solution of this integral may be evaluated easily by graphica methods using the curves of Fig. 3 and a planimeter. The value of the integral for four of the forms of $A_n(t)$ in Fig. 3 is shown in Fig. 5.

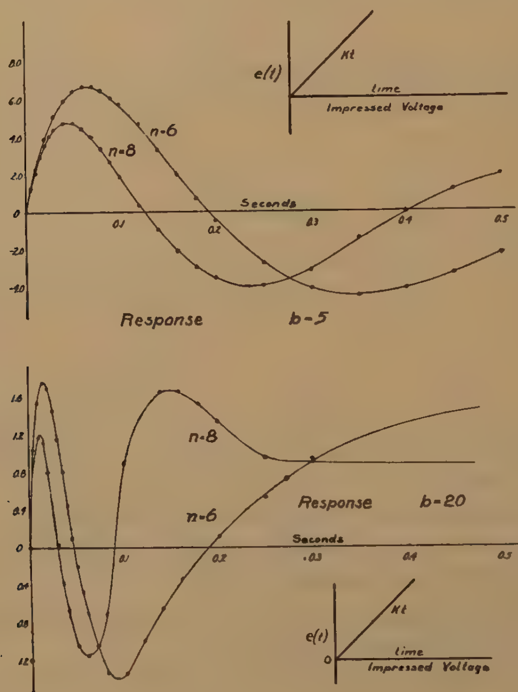

Fig. 5

This, finally, is the response or solution of the amplifier perforn ance for all positive values of time when excited by a voltage of t form $e_1(t) = kt$.

In developing the amplifier response to an impressed voltage of t form in Fig. 1, certain assumptions must be made relative to the phys cal dimensions of the scanning mechanism. The worst practical co ditions met in practice are those for a 24-line system in which there a fifteen scanning cycles per second; that is, these give rise to the mc unfavorable results.

The time required for the square scanning spot in a system of the

limensions to traverse a contrast boundary is 0.000115 second. Displacing the response curves for

$$e_1(t) = Kt \text{ and } e_1(t) = -Kt$$

y this interval of time and plotting the difference curve yields the urve shown in Fig. 6. This is the amplifier response for the growth and onstant portions of the characteristic input voltage. The decay of the esponse can be obtained by adding this curve to its image across the ime axis properly displaced in point of time. The displacement of this urve and its image will be the duration of the constant portion of the nput signal voltage plus 0.000115 second. Fig. 7 gives the amplifier reponse to the characteristic input voltage of Fig. 1 for three periods of

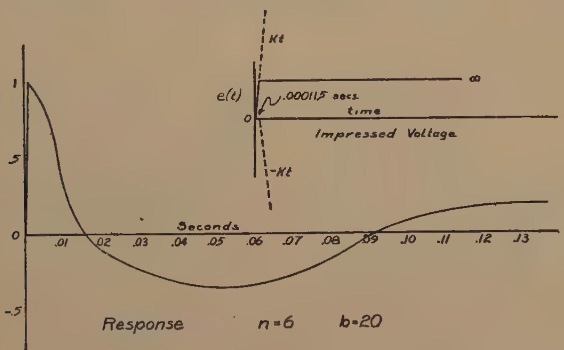

Fig. 6

uration. One gives the response for zero duration of the constant poron. This corresponds to the input voltage due to a square spot traversg a contrast region equal in width to the spot. A second curve shows ie response when the constant portion of the input signal persists for .00266 second. The third example is the response for a duration of .0332 second in the constant portion of the input signal and is roughly ie time required for the spot of a 24-hole, 15-r.p.s. system to cover alf a single scanning cycle.

These examples are constructed on the basis of $n=6$ and $b=20$ hich is an unfavorable time constant. This method indicates the esirability of choosing a low value of b and that an increase in the umber of scanning lines and an increase in scanning speed work no ardship upon the resistance-capacitance coupled amplifier.

Isolating The Distortion Due to Scanning

A casual consideration of the spot method of scanning will disclose ossibilities for considerable distortion. Failure to include the detail

within the area of the scanning spot is primarily the cause of this dis tortion. This is illustrated in Fig. 8 for a square scanning spot travers ing contrast regions of about the same width as the spot itself.

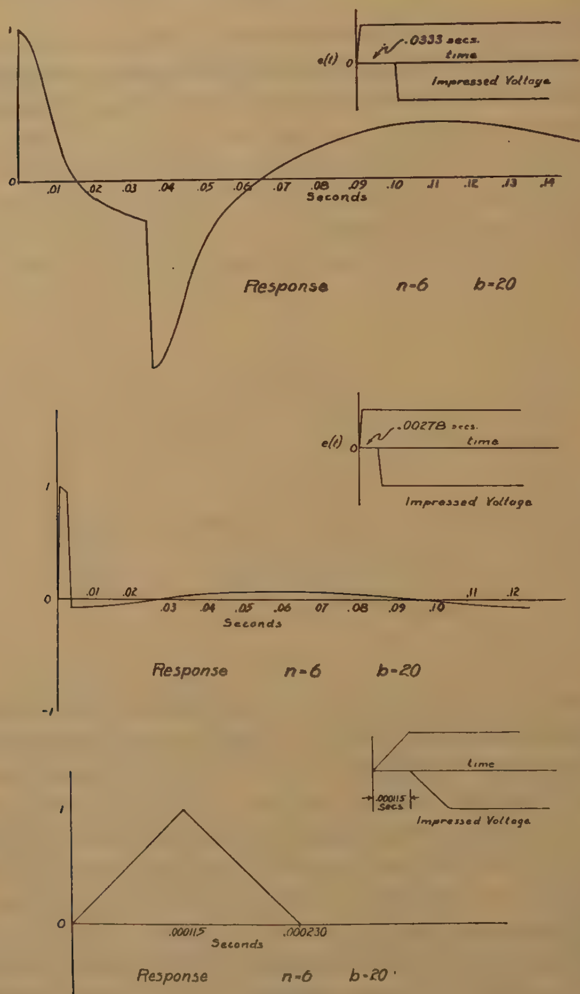

Fig. 7

As a means of demonstrating the effect of this source of distorti graphically, an optical analog of the television scanning system cluding both the sending and receiving elements was devised.[1] T principle of the apparatus is illustrated in Fig. 9. The object scannec

[1] *See* F. Wiedemann, "Der Einflus der Bildpunktzahl auf die Güte von Fe sehbildern," *Fernsehen*, 1, 481–488; November, 1930.

ıthed in light and imaged upon the surface of what corresponds with e sending scanner disk. The light which passes this disk is integrated ı the surface of the second disk corresponding with the receiving anner and the light passing this second disk is allowed to fall upon a ıotographic plate.

Explanation of Optical Analog

The specific purposes of the components of the optical analog e as follows. The lense, L-1, is used to image the directly illuminated

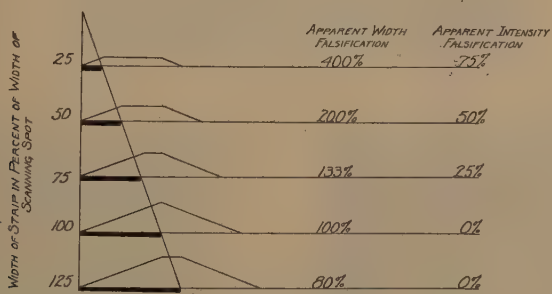

Fig. 8—Distortion in transverse scanning of thin strips.

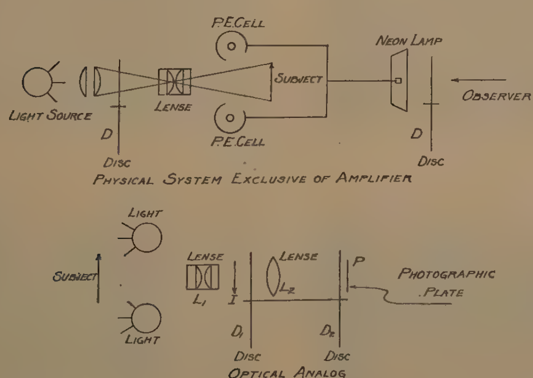

Fig. 9.

bject on the surface of the first scanning disk, D-1. The lense L-2 is ıployed to image L-1 on the surface of the second scanning disk, D-2. ıus a uniformly illuminated region appears on the surface of the cond scanning disk, D-2. The illumination is modulated by the fact at the first scanning disk is interposed between the two lenses. The iform patch of modulated light is scanned by disk D-2 and used expose the surface of a photographic plate immediately behind is disk.

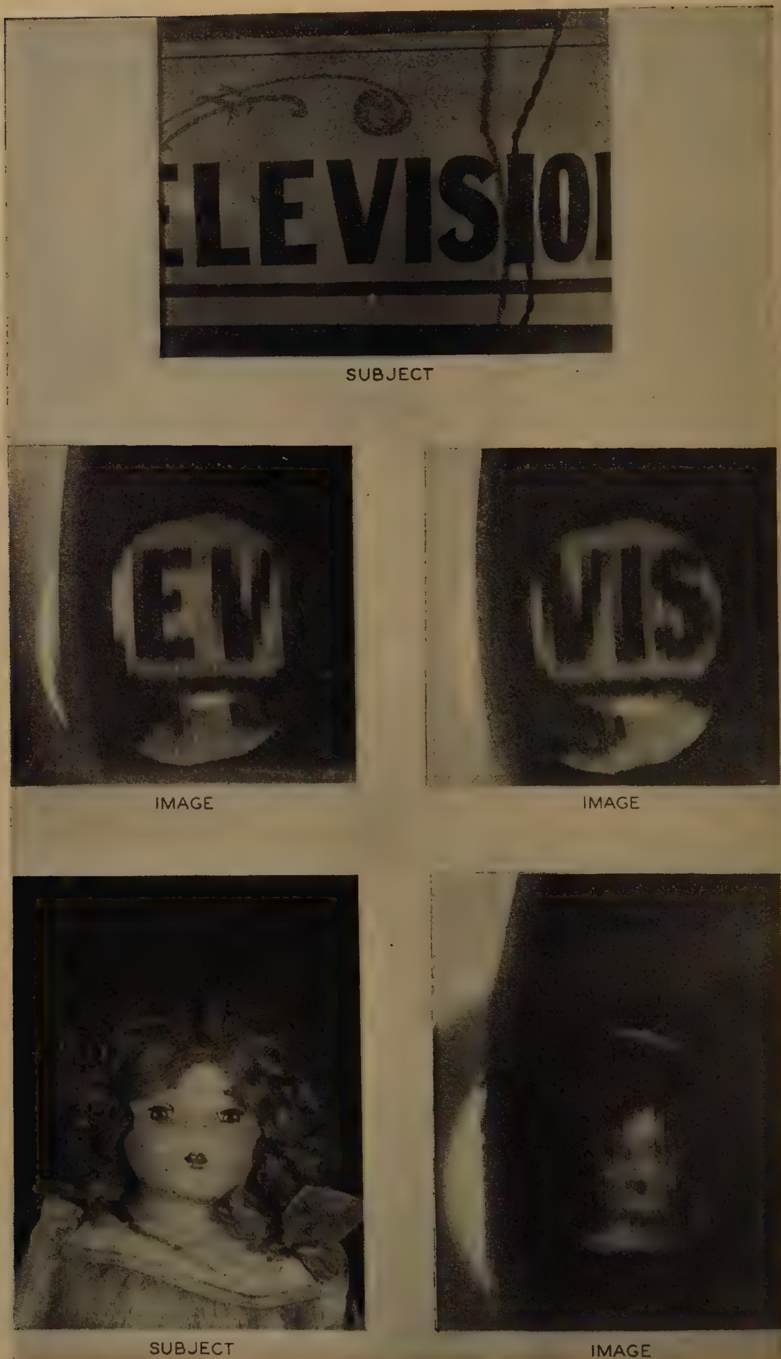

Fig. 10

The disposition of the direct subject illumination becomes analo-gous to the disposition of photocell sensitivity in the actual television apparatus. Examples of the results obtained with the analog are illus-trated in Fig. 10. These are for a 24-line scanning system and they bear a very striking resemblance to the actual results over the system which includes the amplifier.

Conclusion

The amplifier response to the unit impressed voltage is shown to be of an oscillatory nature. The amplifier performance will be good pro-vided the duration of the first positive swing of its response to unit im-pressed voltage is long compared with the duration of the actual tele-vision signal impulse. In general, the greater the time constant of the amplifier, the better. The indication is that the greater the scanning speed the better is the amplifier performance.

These conclusions follow only as a result of this particular analysis. They, however, enjoy some degree of verification in the fairly com-mon experience of television experimenters that systems including only the amplifier perform satisfactorily and without alteration as the disk speed and number of scanning lines are increased.

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A SIMPLE HARMONIC ANALYZER*

By

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Summary—*Some of the difficulties experienced with extensively used methods of harmonic analysis are listed, and a harmonic analyzer more or less free of these defects is described. This analyzer in principle is a dynamometer type meter on which the fundamental and harmonic components of the current are read separately. A theoretical discussion of the method and its limitations is included.*

EXTENSIVELY used methods of harmonic analysis are:

1. Oscillographic method.
2. Tuned circuit method.
3. Beat method.
4. Balancing-out method.

Each of these methods has one or more of the below-listed shortcomings:

1. Inflexible.
2. Slow in operation.
3. Calibration dependent on vacuum tubes.
4. Calibration compressed at small signal end of scale.

The method to be described, besides being relatively free from the above-mentioned shortcomings, possesses the following desirable features:

1. Direct reading.
2. Simple and rapid in operation.
3. Apparatus easily portable.
4. Easily calibrated.
5. Inexpensive.

A harmonic analyzer possessing such characteristics is especially convenient for use in analyzing tube hum voltages, and in measuring the harmonic content of the output of amplifiers and vacuum tubes.

Analyzer in Principle

This analyzer employs as its central element a dynamometer type meter having its zero point in the middle of the scale. Leads from the moving coil and stationary coil are brought out separately and connected in the circuit so that the current to be analyzed flows through

* Decimal classification: 537.7 × R146 Original manuscript received by the Institute, August 3, 1931. Revised manuscript received by the Institute, October 31, 1931.

the stationary coil. The moving coil is connected to a variable frequency audio oscillator, which is tuned to approximately the frequency of the harmonic (or fundamental) of the current being analyzed. When the oscillator is adjusted to within one-tenth cycle per second of the frequency of the component being measured, the pointer of the dynamometer meter will oscillate at a frequency equal to the difference of the two frequencies. Readings of the swing to the left and to the right are taken and averaged to give the value of the current, for the particular frequency being investigated.

The limitations of the analyzer are those imposed by the meters and audio oscillator employed. Presence of harmonics in the output of the audio oscillator gives rise to slight errors which, for a reasonably good oscillator, are small. The accuracy of the analyzer is as good as the accuracy of the meters used.

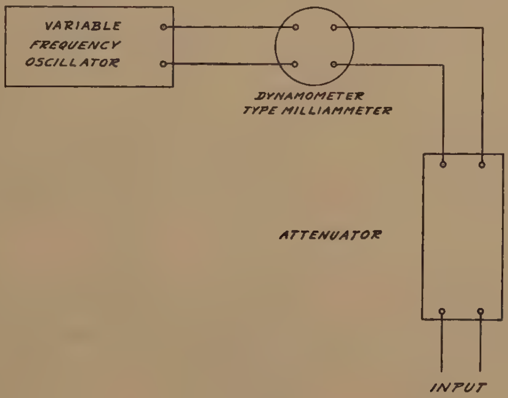

Fig. 1

The block diagram shown in Fig. 1 will serve to acquaint one with the apparatus required for such an analyzer.

A self-contained, compact form of this analyzer has been constructed which has proved itself highly useful. Fig. 2 shows the schematic diagram of the complete analyzer. It will be noted that a dynatron oscillator, $VT1$ and associated tuned circuit, is employed as the source of variable frequency voltage. The dynatron oscillator was chosen as the variable frequency source for this particular analyzer because of its simplicity and stability. The output of the oscillator is passed through a two-stage amplifier, $VT2$, $VT3$, to obtain sufficient undistorted output for the meter. Satisfactory wave form is obtained by proper adjustment of the plate voltage of the dynatron and the use of an amplifier having an increasing attenuation with increasing frequency characteristic. The potentiometer indicated as R_2 functions as

gain control on the amplifier, thus controlling the current applied to the field coil of M_1.

The two meters used are small Hickok dynamometer type instruments which have been somewhat altered. The meter M_1 employed as the "harmonic indicator" was origninally a 0-7 a-c milliameter.

A new scale, reading 3.5–0–3.5 milliamperes, was placed on the meter and its pointer and restoring spring so changed that the pointer when at rest was at the middle of the scale. The meter M_2 used to read the current flowing in the moving coil of the "harmonic indicator" is a 0–7.5-volt range dynamometer which has had its multiplying resistance removed.

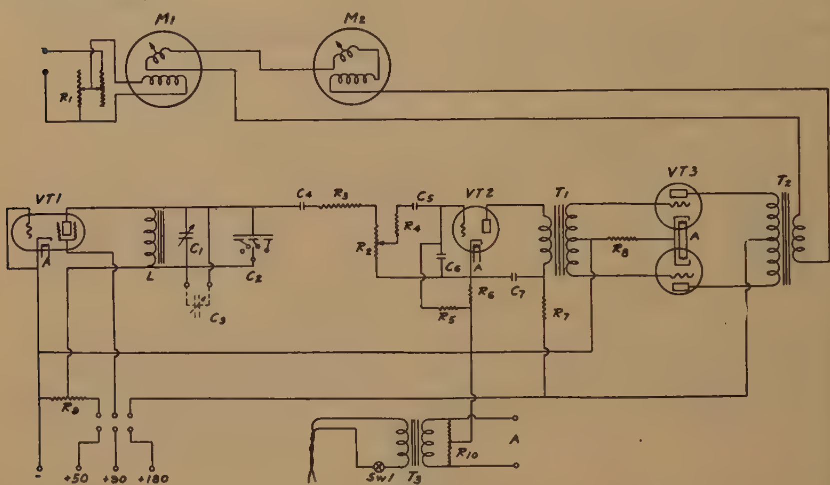

Fig. 2

Calibration was effected by placing a thermocouple meter in series with the stationary coil and adjusting the current in the moving coil until the deflection of the "harmonic indicator" meter coincided with the deflection of the thermocouple meter.

A 400-ohm constant-impedance stepped attenuator, R_1, is used in the input of the "harmonic indicator" to furnish means for multiplying the scale of the instrument.

The entire unit comprising the oscillator, amplifier, meters, and attenuator was built into a case 17 inches × 12 inches × 4 inches. This apparatus has proved itself very useful in measuring the distortion occurring in pentodes. When used for such purpose it was found convenient to employ a 60-cycle signal for the grid of the pentode. To measure the fundamental, 2nd, and 3rd harmonic current, it is necessary

that the dynatron be capable of being tuned from 60 to 180 cycles. This range is convenient for analysis of hum voltages in the output of tubes and radio sets.

Theoretical Discussion

The torque (T_i) acting upon the moving coil at any instant is proportional to the product of the instantaneous currents in the moving coil and stationary coil.[1]

$T_i = K_1 i_1 i_2$
i_1 = current being analyzed.
i_2 = current from oscillator.
K_1 = meter constant, depending upon physical dimensions and the relative position of the two coils. For the present, we will consider it constant for all deflections. (1)

Since the restoring springs in the meter produce a torque directly proportional to the deflection (D),

$D_i = K_2 T_i$
K_2 = spring constant of meter. (2)

If both currents are pure sine waves and both pass through zero at $t=0$

$D_i = K_1 K_2 (\sqrt{2} I_1 \sin \omega_1 t)\ (\sqrt{2} I_2 \sin \omega_2 t)$
I_1 = r-m-s current being analyzed.
I_2 = r-m-s current from oscillator. (3)

Expanding

$$D_i = K_1 K_2 I_1 I_2 [\cos(\omega_1 - \omega_2)t - \cos(\omega_1 + \omega_2)t]. \tag{4}$$

Due to the inertia of the moving coil, with needle and counter-balances attached, the meter will respond only to frequencies up to several cycles per second. Thus we can drop all sums of frequencies $(\omega_1 + \omega_2)$ because they are above 30 cycles per second.

$$D_i = K_1 K_2 I_1 I_2 \cos(\omega_1 - \omega_2)t. \tag{5}$$

Thus for frequencies which are slightly different, the meter pointer will slowly oscillate from one side to the other (the zero point being in the center of the scale). The maximum reading in either direction being

$$D_{\max} = K_1 K_2 I_1 I_2. \tag{6}$$

[1] S. G. Starling, "Electricity and Magnetism," page 241, second edition, fifth impression, 1921.

If the current from the oscillator (I_2) is held to a constant amplitude,

$$D_{max} = K_3 I_1. \tag{7}$$

Thus the deflection may be calibrated directly in milliamperes. The scale is linear for small deflections and is slightly compressed for large deflections, because K_1 of (1) decreases at large deflections (to not less than 80 per cent of that at zero deflection in the ordinary type dynamometer meter). This distribution has a slight advantage over a linear scale in that the per cent error remains more nearly constant throughout the scale.

From the above it is seen that the two frequencies must be within a few cycles per second of each other before the meter pointer will move. As one frequency is varied towards that of the other, the meter pointer will be first seen to blur out slightly, due to it's vibrating faster than the eye can follow, and when the difference of frequencies becomes small enough the needle will be seen to be oscillating. Then by close adjustment the frequencies are made to practically coincide (0.1 of cycle per second or better) so that the maximum deflection (either to the left of zero, or to the right of zero) may be read accurately without the inertia of the moving system of the meter causing an error.

If the current being analyzed is harmonic, it can be represented by a Fourier's series,

$$\begin{aligned} i_1 = {} & \sqrt{2}I_{11} \sin(\omega_1 t + \phi_1) + \sqrt{2}I_{12} \sin(2\omega_1 t + \phi_2) \\ & + \sqrt{2}I_{13} \sin(3\omega_1 t + \phi_3) + \cdots . \end{aligned} \tag{8}$$

Since the phase relations have no effect on the analyzer (variable frequency oscillator), we can simplify to

$$i_1 = \sqrt{2}I_{11} \sin \omega_1 t + \sqrt{2}I_{12} \sin 2\omega_1 t + \sqrt{2}I_{13} \sin 3\omega_1 t + \cdots . \tag{9}$$

Letting $\sqrt{2}I_{21} \sin \omega_2 t$ be the current from the oscillator, and substituting in (1),

$$T_i = 2K_1 I_{21} \sin \omega_2 t [I_{11} \sin \omega_1 t + I_{12} \sin 2\omega_1 t + I_{13} \sin 3\omega_1 t + \cdots] \tag{10}$$

$$D_i = 2K_1 K_2 I_{21} \sin \omega_2 t [I_{11} \sin \omega_1 t + I_{12} \sin 2\omega_1 t + I_{13} \sin 3\omega_1 t + \cdots]. \tag{11}$$

Expanding, and neglecting higher frequency components (sums of frequencies),

$$\begin{aligned} D_i = {} & K_1 K_2 I_{21} I_{11} \cos(\omega_2 - \omega_1)t \\ & + K_1 K_2 I_{21} I_{12} \cos(\omega_2 - 2\omega_1)t \\ & + K_1 K_2 I_{21} I_{13} \cos(\omega_2 - 3\omega_1)t \\ & + \cdots . \end{aligned} \tag{12}$$

Thus to measure the fundamental component we adjust ω_2 to be approximately equal to ω_1; to measure the 2nd harmonic, ω_2 approximately equal to $2\omega_2$, etc. Also from (12) it is readily seen that a harmonic (or the fundamental) cannot affect the reading of another harmonic (or the fundamental) provided the difference in frequency of the two harmonics (or harmonic and fundamental) is greater than the frequency to which the needle of the meter will oscillate. With the meter used in the analyzer this frequency difference should be twenty cycles per second or greater.

Up until now it has been assumed that the current from the oscillator in the analyzer is a pure sine wave. This is not the case, but the effects of its harmonics are negligible, as the following will show. Letting i_1 be the current being analyzed and i_2 the current from the oscillator, neglecting phase relations,

$$i_1 = \sqrt{2}I_{11}\sin\omega_1 t + \sqrt{2}I_{12}\sin 2\omega_1 t + \sqrt{2}I_{13}\sin 3\omega_1 t + \cdots \tag{13}$$

$$i_2 = \sqrt{2}I_{21}\sin\omega_2 t + \sqrt{2}I_{22}\sin 2\omega_2 t + \sqrt{2}I_{23}\sin 3\omega_2 t + \cdots. \tag{14}$$

Leaving out terms representing sums of frequencies,

$$\begin{aligned} D_i = {} & K_1K_2I_{21}I_{11}\cos(\omega_2-\omega_1)t + K_1K_2I_{21}I_{12}\cos(\omega_2-2\omega_1)t \\ & \qquad + K_1K_2I_{21}I_{13}\cos(\omega_2-3\omega_1)t + \cdots \\ & + K_1K_2I_{22}I_{11}\cos(2\omega_2-\omega_1)t + K_1K_2I_{22}I_{12}\cos(2\omega_2-2\omega_1)t \\ & \qquad + K_1K_2I_{22}I_{13}\cos(2\omega_2-3\omega_1)t + \cdots \\ & + K_1K_2I_{23}I_{11}\cos(3\omega_2-\omega_1)t + K_1K_2I_{23}I_{12}\cos(3\omega_2-2\omega_1)t \\ & \qquad + K_1K_2I_{23}I_{13}\cos(3\omega_2-3\omega_1)t + \cdots \\ & + \cdots. \end{aligned} \tag{15}$$

From (17) it is evident that we will get a deflection when a harmonic of the oscillator current has the same frequency as a harmonic of the current being analyzed, and the magnitude of the deflection is proportional to the product of the magnitudes of the harmonics. Thus the deflection is very small and in most cases cannot be seen.

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DISCUSSION ON "SOME EXPERIENCES WITH SHORT-WAVE WIRELESS TELEGRAPHY"*

N. H. Edes

J. C. Coe:[1] Transmission data taken along the Chinese coast and summarized by Captain N. H. Edes was found to be similar in some respects and at variance in others to data accumulated by the writer in the southwestern part of the United States, the range of latitudes in each region being approximately the same. Transmissions were over distances up to 900 miles east and west as well as north and south in the region between the 27th and 41st latitudes, and comprising Texas, Oklahoma, New Mexico, Colorado, Wyoming, Arizona, and southern California, most of which is arid and at a considerable elevation above sea level, in contrast to conditions along the Chinese coast line.

No discontinuity in the distance-wavelength characteristic was found. However, there was a considerable range in wavelength which could be used in transmitting a given distance. The minimum wavelength from a transmitting station which could be heard at the receiving station was found to vary greatly. In general the use of a wavelength just high enough to be heard resulted in a strong signal, but was subject to extreme fading, making reception erratic and limited to fewer hours per day than a wavelength somewhat higher. The signal strength in the case of the higher wavelength being less suggested a greater attenuation due to the return of the ray to earth at a lesser distance from the transmitter.

Some points in agreement with those observed in China are as follows:

(a) The general shapes of the daylight range-best wavelength diagrams are very similar.

(b) The best wavelength for a given distance under summer daylight conditions was very nearly the same as that for winter daylight conditions.

(c) The height of the layer of high ionization was found to vary throughout a wide range at night, as pointed out by Captain Edes in a previous paper.[2]

Some points of difference are as follows:

(a) The wavelengths required in the southwest are about ten meters higher than those shown for summer and winter daylight conditions. The empirical expression for the best wavelength for daylight conditions was given as:

$$\lambda = 0.046(1120 - d) \qquad (1)$$

in which the distance was taken from 100 to 800 miles. In order to fit the conditions in the southwest the constants were modified:

$$\lambda = 0.027(2000 - d). \qquad (2)$$

However, this equation would not apply for distances under 200 miles or over 1000 miles since the relation ceases to be linear beyond these limits, the wavelengths given by this equation are too low beyond these limits, the curve rising rapidly as distance was decreased under 200 miles, and becoming more nearly horizontal over 1000 miles.

(b) Instead of finding the height of the layer of high ionization to be fairly constant by daylight, it was noted that in the southwest the height of this layer

* Proc. I. R. E., 18, 2011; December, 1930.
[1] Aircraft Radio Laboratory, Wright Field, Dayton, Ohio.
[2] Proc I. R. E., 19, 1663; September, 1931.

was subject to great variation, being from approximately 210 to 350 km. These figures were computed from the minimum wavelengths which could be heard at various stations.

(c) From observations in the southwest it was concluded that fading in the zone at which the sky ray first returns to earth is due to the variation in this distance, and consequently in the height of the layer of ionization. Transmissions at wavelengths from 30 to 200 meters and at distances up to 40 miles, and well within the range of the ground ray showed that the distance at which fading usually became pronounced increased approximately as the square of the wavelength. This is contrary to results which would be expected if this fading were caused by the interaction of the ground ray with a sky ray from a single layer, since the sky ray of the shorter wavelengths would not be expected to return to earth at a distance less than those of the longer wavelengths. Even if the attenuation of the ground rays of the various wavelengths is considered, this would not account for the difference in distances free from fading. Furthermore, these short distances were entirely different from those at which the useful sky ray returned to earth.

N. H. Edes[3]: The points of agreement between Mr. J. C. Coe's observations and those of the author encourage the belief that the general nature of the propagation characteristics has been established for the distances and latitudes in question. The points of difference are interesting, for they may help to show what geophysical factors determine the characteristics. The study of differences such as these may eventually lead to the formulation of a law.

Mr. Coe points out the contrast between the damp, low-lying country of the China coast and the high, arid country of the southwestern part of the United States. The author considers that the difference in soil and in height above sea level would have little effect at the medium distances, for at these distances the ground ray is negligible and the sky ray is not nearly tangential to the earth (except perhaps in summer darkness). But the difference in climatic conditions may well enter into the problem. It may be that the height and ionization of a reflecting or refracting layer are partly determined by local climatic conditions.

Mr. Coe found no discontinuities in the distance-wavelength characteristics. He was working over distances up to about 900 miles. Now the author's deductions from the curves obtained in China indicate discontinuities at about 2100 miles in daylight, 900 miles in winter darkness and 450 miles in summer darkness.[2] If the conditions in the southwestern states were similar, one might, therefore, have expected a discontinuity at about 450 miles at night in summer. The other discontinuities may have fallen outside the area covered by Mr. Coe's experiments.

The discontinuity at 450 miles for summer darkness was considered by the author to be due to a low-lying layer of small ionization. May we deduce that such a layer was present in China but not in America? The author found the height of the layer to be about 10 km, which locates the layer as lying not much above cloud level. May the presence of such a layer be due to the high humidity along the China coast?

Mr. Coe's observations as to the strong signals but extreme fading obtained with a wavelength just above skip wavelength are in agreement with the author's experience and with his paper in the PROCEEDINGS for June, 1931. The author

[3] Royal Signals, attached to Royal Canadian Signals, Camp Borden, Ontario, Canada.

agrees that signal strength falls off as the wavelength is increased beyond a certain point above skip wavelength. But he suggests that this is because the ray suffers absorption in penetrating into the layer which turns it back, and in passing through such regions of ionization as may lie below that layer;[4] such absorption increases with the wavelength.

To take Mr. Coe's points of difference in detail: (a) Mr. Coe modifies the author's formula for best wavelength in daylight so as to fit conditions in the southwestern states. The modified formula gives wavelengths which are greater than the author's by about 6 meters at 200 miles and 18 meters at 800 miles. The author claims no great accuracy for his original results, but considers that the error in them was probably not more than 2 meters. To what then should we attribute the divergence? It seems that there are two main alternative explanations:

(1) Permanent differences between the two regions.

(2) A general variation in conditions during the time elapsing between the author's experiments and those of Mr. Coe. Mr. Coe does not say in which year his data were collected. It is known that best wavelength varies somewhat from year to year.

The author agrees that the linear formula given by him, and Mr. Coe's modification of it, will apply for the middle distances only. As shown in the paper in the PROCEEDINGS for September, 1931, the skip-distance curve flattens out with increase of distance. The best-wavelength curve must conform since it lies above the curve for skip wavelength. At the short distances it is difficult to separate the effects of the sky ray from those of the ground ray.

While the best-wavelength curve is useful for purposes of radio engineering, the skip-wavelength curve is perhaps more interesting since from it we can derive the parameters of the layer instrumental in returning the waves. Can Mr. Coe give the approximate equation of the linear part of his skip-wavelength curve, or better still a complete graph? If the author's theory is valid this would permit estimation of the height and ionization of the layer in America.

It may be remarked that the linear parts of the best-wavelength curves of Mr. Coe and of the author would, if prolonged, meet nearly on the axis of λ. Mr. Coe's curve has a slope of rather more than half that of the author's. If it may be inferred that the skip-wavelength curves conform somewhat similarly, then the layer ionizations in China and the southwestern states are of the same order of magnitude, but the layer in the States is at a greater height. The author's prediction that the characteristics would be almost identical for a given zone of latitude seems to need modification.

(b) Mr. Coe states that he found large variations in the height of the layer which is operative in daylight. Were these variations as between different pairs of stations, the pairs being at different distances? Or were they variations observed at a given pair of stations throughout the day, or from day to day?

The author's data took little account of variations throughout the day or from day to day since, it may be remembered, they were obtained for conditions of full daylight or full darkness averaged over a fortnight. The only variations taken into account were, therefore, those between day and night and between summer and winter. The author agrees that the minimum wavelength varies throughout the day or night and between successive days. This shows a variation

[4] Cf. E. V. Appleton, "On some measurements of the equivalent height of the atmospheric ionised layer," *Proc. Royal Soc.*, A., 126, 566–567, 1930.

of either the height of the layer or of its ionization or of both. Mr. Coe does not state the method he used for computing the height of the layer from the skip wavelengths. Did he use a method similar to the author's which took account of the earth's curvature but made certain assumptions which may or may not have been justified?

(c) The author agrees that fading in the zone where the sky ray first returns to earth may be due to variation of skip distance. This variation would in turn be due to variation of the height or ionization of the layer. Mr. Coe's observations at distances within the influence of the ground ray and within the skip distance are difficult to explain. The only possible explanations seem to be (1) fluctuation in strength of the ground ray, (2) interference between the ground ray and a ray that has encircled the earth. Yet neither explanation seems probable.

Finally, Mr. Coe has evidently accumulated some very valuable data. The author would respectfully urge him to publish them in full. The complete curves for skip wavelength, best wavelength, and upper limiting wavelength would be of particular interest.

BOOK REVIEW

Servicing Superheterodynes, by John F. Rider, 1931, 161 pages, Radio Treatise Company, Inc., New York.

This book is intended as a brief manual to assist in the servicing of superheterodyne receivers. It contains a great variety of data which should be valuable in this kind of work. There is an easily understood discussion of superheterodyne principles and circuits. Many partial and several complete circuit diagrams are included by way of illustration. One chapter is devoted to simple rules for trouble-shooting. A good share of the data has been obtained from superheterodyne receivers of very recent design and manufacture, so that the book is recommended for its up-to-date general information.

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BOOKLETS, CATALOGS, AND PAMPHLETS RECEIVED

Copies of the publications listed on this page may be obtained gratis by addressing a request to the manufacturer or publisher.

A series of vacuum tube microammeters, milliammeters, millivoltmeters, and voltmeters manufactured by the Rawson Electrical Instrument Co., Cambridge, Mass., are described in an eight-page catalog entitled "Rawson Electronic Meters". The meters are intended for alternating-current and voltage measurements only, the type 602-A meters operating from 25 cycles to 10 kilocycles and the type 602-B having an upper limit of 100 kilocycles. The meters are available in several ranges from full-scale ranges to 1 microampere and 10 millivolts to 1 ampere and 1000 volts. All meters may be temporarily considerably overloaded. The accuracy which may be expected from these meters is not stated.

Bulletin RC-118 published by the Webster Electric Co. of Racine, Wis., describes a completely alternating-current operated four-stage audio amplifier using a pair of 250 tubes in the final stage. The equipment is intended for use in theaters having a seating capacity up to 1000, and is designed to be used with sound on film projection equipment.

A sixteen-page booklet entitled "Weston Photronic Cell" gives considerable technical data on the photronic. The spectral response of the cell is somewhat similar to that of the human eye, except that it is more sensitive at the blue and red regions and the response extends well into the ultra-violet and infra-red regions. A separate folder which shows the use of this cell for light control purposes and describes a power relay as well as a sensitive relay which is operated directly from the photo cell, is also available from the Weston Electrical Instrument Co., Newark, N. J.

The Parker-Kalon Corporation, 200 Varick St., New York, N .Y., has recently issued a 30-page catalog describing the various types of self-tapping metal screws and nails. Products of various types for fastening sheet metal, castings, metal to wood, and masonry are described, and the catalog is well illustrated to show the various application of the various types of fasteners.

"Cinch Radio Products" is the name of a folder published by the Cinch Manufacturing Corporation, 2335 West Van Buren St., Chicago, Ill., describing four- and five-prong vacuum tube sockets, binding post assemblies, phone tip jacks, and binding post mounting strips. The products described are intended largely for use by manufacturers.

The Premier Crystal Laboratories, 74 Cortlandt St., New York, N. Y., has issued a folder of instructions for grinding and finishing quartz blanks and crystals which should be of interest to those working with crystal controlled oscillating circuits.

Bulletin 5501 of the Ward Leonard Electric Co., Mount Vernon, N. Y., describes a number of voltage regulating transformers which are intended to supply constant voltage to exciter lamps used in phototube operation. Transformers are available in stock sizes from 10 watts to 100 watts.

A thirty-two page catalog issued by the Polymet Manufacturing Co., 829 East 134th St., New York, N. Y., lists the complete line of Polymet resistors, condensers, and transformers. Although many of the products are designed for set manufacturers, there are also a number of items designed for replacement purposes by the serviceman.

RADIO ABSTRACTS AND REFERENCES

THIS is prepared monthly by the Bureau of Standards*, and is intended to cover the more important papers of interest to the professional radio engineer which have recently appeared in periodicals, books, etc. The number at the left of each reference classifies the reference by subject, in accordance with the "Classification of Radio Subjects: An Extension of the Dewey Decimal System," Bureau of Standards Circular No. 385, obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 10 cents a copy. The classification also appeared in full on pp. 1433–56 of the August, 1930 issue of the PROCEEDINGS of the Institute of Radio Engineers.

The articles listed are not obtainable from the Government or the Institute of Radio Engineers, except when publications thereof. The various periodicals can be secured from their publishers and can be consulted at large public libraries.

R000. RADIO (GENERAL)

R000 A. S. Angwin. Radio telegraphy and radio telephony. *Jour. I.E.E.* (London), **70**, 145–152; January, 1932.

Review of technical progress in the engineering practice of radio.

R100. RADIO PRINCIPLES

R113.5 L. W. Austin. Solar activity and radiotelegraphy. PROC. I.R.E., **20**, 280–285; February, 1932.

This report to the International Research Council on solar and radio relationships shows that the relationships are closer at high frequencies than at low, that the effect of magnetic storms, which are assumed to be due to solar action, is, in general, to weaken night signals at all frequencies and in the medium and low frequency ranges to strengthen day signals. Curves are given.

R113.61 E. V. Appleton and G. Builder. Wireless echoes of short delay. *Proc. Phys. Soc.* (London), **44**, 76–78; January 1, 1932.

An account of a simple method of producing short pulses of radio-frequency energy is given, together with notes on its application in the investigation of radio echoes of short delay. Frequency-change and group-retardation methods are compared.

R113.61 T. R. Gilliland, G. W. Kenrick, and K. A. Norton. Investigations of Kennelly-Heaviside layer heights for frequencies between 1600 and 8650 kilocycles per second. *Bureau of Standards Journal of Research*, **7**, 1083–1104; December, 1931. PROC. I.R.E., **20**, 286–309; February, 1932.

Abstracted in February, 1932 issue of PROCEEDINGS of the Institute of Radio Engineers.

R116 L. Tonks. Impedance characteristics of loaded Lecher systems. *Physics*, **2**, 1–11; January, 1932.

Simple formulas are developed for the impedance of short lengths of Lecher systems terminated with resistances. The variation of impedance with system length is traced and certain simple relationships are found. A method of calculating resistance from a resonance curve is derived.

R120
×R320 A. W. Ladner. A graphical synthesis of aerial arrays. *Marconi Review*, No. **33**, 11–18; November-December, 1931.

This article describes a simple method of calculating graphically the polar diagrams, both in a vertical and horizontal plane, of any array of spaced antennas.

* This list compiled by Mr. A. H. Hodge, Mr. W. H. Orton and Miss E. M. Zandonini.

R133 J. D. Crawford. Aspects of standard-signal generator design. *Electronics,* **4**, 46–47; February, 1932.

A discussion is made from the designer's view-point of some of the problems encountered in standard-signal generator design.

R139 W. Jackson. The transient response of the triode valve equivalent network. *Phil. Mag.* **13**, 143–153; January, 1932.

A mathematical treatment of the equivalent network is given.

R140 E. K. Sandeman. Lining up broadcasting circuits. *Electrical Communications,* **10**, 131–133; January, 1932.

A method of measuring line equivalents and adjusting levels in telephone and telegraph lines is given, which meets the recommendations of the C.C.I., and which has substantially all the advantages of the constant voltage method.

R140 P. K. Turner. Designing detector circuits. *Wireless World and Radio Review,* **30**, 132–134; February 10, 1932.

A set of curves which facilitate calculations in designing detector circuits are given.

R143 ×R386 F. S. Dellenbaugh and R. S. Quimby. The important first choke in high-voltage rectifier circuits. *QST*, **16**, 14–19; February, 1932.

Filter problems peculiar to modern rectifiers are treated.

R143 N. R. Bligh. The design of the band pass filter. *Wireless Engineer and Experimental Wireless,* **9**, 61–66; February, 1932.

Circuits, equations, and experimental data which should be very useful in designing filters are given. The treatment is practical and comprehensive.

R146 Y. Kusunose. Elimination of harmonics in vacuum tube transmitters. Proc. I.R.E., **20**, 340–345; February, 1932.

A brief description is given on the present state of technique concerning the suppression of harmonics radiated from vacuum tube transmitters. A simple method of eliminating the strongest one of the harmonics is suggested.

R152 ×R325.31 C. T. Solt. The development and application of marine radio direction finding equipment by the United States Coast Guard. Proc. I.R.E., **20**, 228–260; February, 1932.

The object of this paper is to present a résumé of the results obtained with modern equipment under the actual conditions encountered in service use, accompanied by such notes and comments by the author as are deemed of interest to those concerned with the development, improvement, and application of marine and aircraft radio direction finders. The fundamental principles underlying the art of direction finding by means of radio are not recounted as it is realized the reader has available numerous current publications on the subject.

R165 I. Wolff. Calculation of loud speaker efficiency. *Electronics,* **4**, 52–53; February, 1932.

Equations, calculations, and data are given.

R165 N. W. McLachlan. Additional experiments on moving-coil reproducers and on flexible disks. *Phil. Mag.* **13**, 116–143; January, 1932.

Various details of the moving coil reproducers are discussed. A series of experiments is outlined, showing the influence of reinforcing certain portions of the diaphragm.

R200. Radio Measurements and Standardization

R200 C. E. Webb. Moving magnets.—Precision measurements of the gap flux density. *Wireless Engineer and Experimental Wireless,* **9**, 67–69; February, 1932.

A short note on the method employed at the National Physical Laboratory for measuring flux densities is given.

R214 ×R281 W. A. Marrison. Quartz crystal resonators. *Bell Laboratories, Record,* **10**, 194–199; February, 1932.

The uses of quartz for piezo-electric standards of frequency are discussed. Mention is made of the method of cutting and mode of excitation.

R214 L. B. Hallman, Jr. Notes on the frequency stability of quartz plates. *Radio Engineering,* **12**, 15–19; February, 1932.

This article summarizes a representative portion of the published material on the subject of quartz piezo-electric oscillators. It contains some statements relative to effect of adjustment of air gap, and effect of jarring crystal which are probably incomplete.

R214 V. E. Heaton and E. G. Lapham. Quartz plate mountings and temperature control for piezo oscillators. *Bureau of Standards Journal of Research,* **7**, 683–690; October, 1931. Proc. I.R.E., **20**, 261–271; February, 1932.

Abstracted in December, 1931, issue of the Proceedings of the Institute of Radio Engineers.

R214 B. Decaux. Visite de qualques laboratoires Étrangers a l'occasion de comparaisons internationales de fréquence. (An account of visits to some foreign laboratories for the purpose of making international comparisons of frequency.) *L'Onde Electrique,* **10**, 521–540; December, 1931.

The L.N.R. carried a piezo oscillator to German, Italian, and English laboratories. Results of frequency comparisons in these laboratories are described.

R242.12 J. R. Roebuck. A sensitive flexible thermostat. *Rev. of Sci. Inst.,* **3**, 93–100; February, 1932.

Description is given of a constant temperature device which utilizes the temperature change of resistance of one or two coils of wire in order to unbalance a Wheatstone bridge whose galvanometer controls the heating current by means of a photoelectric cell and vacuum-tube current amplifier.

R251 ×621.375.1 J. Groszkowski. La mesure du rendement des générateurs a lampes a l'aide du photo-element. (The measurement of efficiency of electron-tube generators with the aid of a photo-electric cell). *L'Onde Electrique,* **10**, 541–545; December, 1931.

A description is given of a method for measuring the power dissipated in the plate of air-cooled electron tubes with the aid of a photo-electric tube "Cu_2OCu" which is sensitive to infra-red radiation.

R300. Radio Apparatus and Equipment

R320 N. Wells. Feeder adjustments for short wave vertical aerials. *Marconi Review,* **33**, 1–10; November-December, 1931.

This treats the problem of matching the impedance at the base of an antenna to the natural or surge impedance of a particular form of feeder, the Marconi concentric type.

R330 W. Charton. Vacuum-tube performance vs. manufacturing tolerances. *Electronics,* **4**, 44–45; February, 1932.

The effects of such irregularities as develop in production are treated.

R339 C. F. Stromeyer. Two sets of elements in one tube. *Radio Engineering,* **12**, 39–40; February, 1932.

The theory of operation and applications of the triple-twin tube are discussed.

R339 E. J. C. Dixon. The Heptode—A novel thermionic valve. *The Post Office Electrical Engineers' Journal* (London), **24**, 299–302; January, 1932.

A transmitting tube is described with seven electrodes which replace two tubes in the push-pull circuit. It has a plate dissipation of 250 watts per plate, and has little tendency toward self oscillation.

R339 L. Martin. The positive-grid tube. *Radio Craft*, **3**, 523; March, 1931.

A tube is described which works as a class "B" amplifier and delivers 20 watts of undistorted output.

R355.21 D. B. Mirk. The Prague high power broadcasting equipment. *Electrical Communication*, **10**, 106–130; January, 1932.

A careful description of the 200-kw station and equipment is given.

R355.3 O. M. Hovgaard. A transmitter for the Coast Guard. *Bell Laboratories Record*, **10**, 205–208; February, 1932.

A 35-watt telephone or continuous-wave transmitter is described. This transmitter is compact and is intended for use on Coast Guard ships.

R355.4 ×R423.4 Portable beacon transmitter in the Army. *Radio Engineering*, **12**, 37; February, 1932.

A portable beacon transmitter is described.

R355.5 Broadcasting with ultra-short waves. *Wireless Engineer and Experimental Wireless*, **9**, 59–60; February, 1932.

Brief discussion of work done on ultra-short waves is given.

R355.6 Y. Kusunose and S. Ishikawa. Frequency stabilization of radio transmitters. Proc. I.R.E., **20**, 310–339; February, 1932.

The quartz-controlled oscillator is recognized as the best means of accurate maintenance of frequency. Several other methods may be used when the frequency stability may be as low as 0.01 per cent. These methods are described.

R355.9 E. G. Lapham. An improved audio-frequency generator. *Bureau of Standards Journal of Research*, **7**, 691–695; October, 1931. Proc. I.R.E., **20**, 272–279; February, 1932.

Abstracted in the December, 1931, issue of the Proceedings of the Institute of Radio Engineers.

R355.9 E. G. Fraim. A direct-coupled amplifier for the dynatron oscillator. *QST*, **16**, 37–38; February, 1932.

An oscillator and radio-frequency amplifier are described which will eliminate the frequency drift of a dynatron, retaining stability in operation and giving sufficient output to use the harmonics for frequency measurement.

R357 C. K. Stedman. A thermionic frequency doubler. *Physics*, **2**, 42–47; January, 1932.

A frequency doubler is described which has an output that is proportional to e_g^2 alone. This is accomplished by combining the output of two tubes which are operating on different parts of the grid voltage plate current characteristic curve.

R361 R. A. Hull. An unorthodox receiver. *QST*, **16**, 9–13; February, 1932.

Considerations involved in planning and building an advanced type of high-frequency receiving set are given.

R361 L. E. Barton and L. T. Fowler. An efficient battery-operated radio receiver. *Radio Engineering*, **12**, 23–24; February, 1932.

A highly developed, self-powered radio receiving set using batteries is described.

R361 McM. Silver. A new short wave receiver. *Radio Craft*, **3**, 528–529; March, 1932.

A new Silver Marshall short wave receiving set is discussed.

R361.2 A. L. M. Sowerby. "Ganging" the tuning controls of a superheterodyne receiver. *Wireless Engineer and Experimental Wireless*, **9**, 70–75; February, 1932.

Three methods of ganging are mentioned. The third method is discussed. It has all tuning condensers alike but for the oscillator the law is modified by a combination of series and parallel fixed condensers.

R366 W. W. Garstang. A new voltage quadrupler. *Electronics*, **4**, 50–51; February, 1932.

A circuit and circuit constants are given for quadrupling an a-c voltage. The voltage doubler is also treated. Dry electrolytic condensers make the circuit practicable.

R366.1 ×621.353 F. T. Bowditch. Battery design problems of the air cell receiver. Proc. I.R.E., **20**, 215–227; February, 1932.

The present paper deals with those design features of battery-operated radio receivers which are important from the standpoint of obtaining the maximum useful battery life. The properties of the air cell A battery are discussed with relation to receiver design.

R381 W. W. Garstang. Electrolytic variable condensers. *Radio Craft*, **3**, 531; March, 1932.

A variable high capacity condenser is described.

R382 H. C. Rentschler and D. E. Henry. An improved high resistance unit. *Rev. Sci. Inst.*, **3**, 91–92; February, 1932.

A method of making resistors which pass current proportional to voltage applied and have resistances as great as several hundred thousand megohms is given.

R390 N. M. Rust. An application of the circle diagram to the design of attenuation and phase equalizers. *Marconi Review*, No. 33, 19–28; November-December, 1931.

The adjustment of the values of the resistances of the capacity and inductance in such a way that the total impedance across the circuit is constant for all frequencies is applied to the design of attenuation and phase correcting networks.

R500. Applications of Radio

R525 H. Diamond and G. L. Davies. Characteristics of airplane antennas for radio range-beacon reception. *Bureau of Standards Journal of Research*, **6**, 901–916; May, 1931. Proc. I.R.E., **20**, 346–358; February, 1932.

Abstracted in July, 1931, issue of the Proceedings of the Institute of Radio Engineers.

R526 H. C. Leuteritz. Radio communication on the international airlines. *Radio Engineering*, **12**, 25–29; February, 1932.

Design of radio equipment and operating problems of the most extensive airways radio communication system in the world are discussed.

R531.6 Speed of signal transmission over carrier telegraph channels. *The Post Office Electrical Engineers' Journal* (London), **24**, 269–270; January, 1932.

Results are given of a measurement of speed of transmission of signals over 36,440 miles of circuit.

R531.6 F. E. Nancarrow and H. Stanesby. A continuously loaded cable for use at high frequencies. *The Post Office Electrical Engineers' Journal* (London), **24**, 296–298; January, 1932.

This article describes and gives the results of electrical tests on a continuously loaded cable developed for use at receiving stations of the long wave transatlantic telephony circuit.

R566 A. J. Kavanaugh. Police radio system an efficient tool of law enforcement. *Radio Engineering*, **12**, 30–32; February, 1932.

A description of the installation and operation of the radio police equipment of Rochester, New York, is given.

R592 ×R361 O. Block. Improving an auto radio. *Radio Craft*, **3**, 526; March, 1932.

In this article, the author outlines some of the problems that were encountered in the design of an automobile receiver and describes the methods of eliminating them.

R592 H. G. Cisin. The screen-grid six. *Radio Craft*, **3**, 530; March, 1932.

Construction data for a six tube, screen-grid automobile receiver is given.

R800. NONRADIO SUBJECTS

535.38 C. E. Ellis. Photocell controlled elevator doors. *Electronics*, **4**, 54–55; February, 1932.

Description of installation and method of operation.

535.38 S. Asao. Photoelectric properties of thin films of alkali metals. *Physics*, **2**, 12–20; January, 1932.

Measurements are reported on the color sensitivities of various photoelectric tubes having cathodes made of alkali metals.

621.313 A. B. Lewis. A clock-controlled constant-frequency generator. *Bureau of Standards Journal of Research*, **8**, 141–157; January, 1932.

A synchronous motor generator set is described whose frequency is kept constant by a clock-tuning fork synchronoscope.

621.313.7 L. J. Barnes. Characteristic curves of the aluminum rectifying cell. *Phil. Mag.*, **13**, 76–81; January, 1932.

The cell characteristics are outlined as an indication of the manner in which the optimum conditions for its working can be determined.

621.385.96 G. Lewin. Frequency characteristics in film recording and reproducing. *Electronics*, **4**, 40–43; February, 1932.

This article concerns itself only with frequency characteristics of film recording by the light valve method. The recording, processing, and reproduction of the film record are discussed.

621.388 La television sous-marine. (Undersea television). *La Nature*, No. **2874**, 101–102; February, 1932.

A description of a device intended to explore the undersea is given.

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